PRINCIPLES OF SANITARY SCIENCE AND THE PUBLIC HEALTH

Principles of Sanitary Science and the Public Health

WITH SPECIAL REFERENCE TO

THE CAUSATION AND PREVENTION OF INFECTIOUS DISEASES

BY

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"*With all deductions, the triumphs of sanitary reform as well as of medical science are perhaps the brightest page in the history of our century.*" — W. E. H. LECKY

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TO

The State Board of Health
of Massachusetts

FAITHFUL THOUGH UNPAID GUARDIANS OF THE PEOPLE
IN WHOSE HONORABLE SERVICE
THE AUTHOR BEGAN AN ACQUAINTANCE WITH PUBLIC HYGIENE
AND STRENGTHENED A LOVE FOR SANITARY SCIENCE
WHICH HAVE INCITED HIM TO WRITE THIS BOOK

AND ESPECIALLY

TO

Henry Pickering Walcott, M.D., Chairman

AND

Hiram Francis Mills, C.E., Engineer Member

"Even to the State's best health."
— TIMON OF ATHENS

PREFACE

With the single exception of the change effected by the acceptance of the theory of organic evolution, there has probably been no modification of human opinion within the nineteenth century more wonderful, or more profoundly affecting the general conduct of human life, than that in our attitude toward the nature, the causation and the prevention of disease. The modern conception of the living body, whether plant or animal, as essentially a physical mechanism, is largely the result of discoveries in the domain of physics and chemistry begun, indeed, but not perfected, before the recent century. The modern conception of disease as due to imperfection, misbehavior or disturbance of a physical mechanism depended for its development on an acquaintance with the physiology of the body and its microscopic structure which did not exist before the introduction, in the third decade, of the achromatic objective. The microscopical renaissance which began with this pregnant invention speedily led to discoveries of the first importance in the normal structure of organized bodies; disclosed in abnormal tissues the material ravages, and, in some cases, the parasitic origin of disease; brought into full view a flora and a fauna hitherto unseen or only half seen; and, by the end of the fifth decade, was throwing a new and increasingly powerful light on the long-vexed question of the relation of ferments and fermentation to decomposition, putrefaction and disease. At the end of the sixth decade a new theory of infectious disease — the "germ" theory — had arisen,

and in the hands of Pasteur, Lister and many others was already bearing fruit.

The last quarter of the century has witnessed the firm establishment and fruitful development of these several conceptions. The principal theories to which they have given birth have been thoroughly tested, and stand to-day for the most part as accepted scientific principles; while their applications to the practical conduct of life have everywhere been followed by results of extraordinary interest and importance. Public hygiene and state medicine have become subjects compelling the attention of statesmen and affecting the welfare of nations. Sanitary law has been endowed with unusual privileges and powers, and sanitary regulations controlling the commerce of the civilized world are debated in international congresses. Sanitary science and preventive medicine, terms practically unknown before this century, have become almost household words. Sanitary arts of great range and importance have grown up; vast sums are annually spent for private, and especially for public, sanitation; and human life has been made safer, longer and probably happier.

Standing on the threshold of the twentieth century, and surrounded by the innumerable municipal, medical, domestic, public and private sanitary safeguards which have already sprung from these discoveries so that, in spite of facilities for the spread of disease by the development of easy international transportation, such as the world has never before known, pestilences and plagues are no longer greatly dreaded, it is hard to realize that our not very remote ancestors regarded disease as an insoluble mystery, an inscrutable visitation of divine Providence, or as the penalty and consequence of sin. Under such beliefs there could be no sanitary science. But if disease be disturbance of a physical mechanism, and due to the fact that the mechanism is made of poor materials, or of good materials badly put together, or that it is badly operated, or

that it is interfered with by unfavorable environmental conditions, it becomes easy to comprehend at least approximately the causes of diseases, and in many cases to remove or forestall them. It is precisely this which the science and art of hygiene seek to do, namely, to comprehend the nature of the human body and its diseases, in order as far as possible to prevent the latter. Hygiene is the science and art of the conservation and improvement of normal living, the prevention not merely of premature death but of abnormal life; and sanitary science, or hygiology, is simply the body of scientific doctrine, or the principles, underlying the sanitary arts.

The time has not yet come for a scientific treatise on the whole subject of hygiene. The application of many of the results of experimental science to the welfare of man, extensive and valuable though they are, must still wait until their relations to everyday life become clearer. Climatology, clothing, warming and ventilation, foods and feeding are subjects undoubtedly of the very first importance, but not as yet reducible in their relation to human life to simple scientific terms. It is otherwise, however, with an important class of diseases proceeding from the controllable environment and known as "communicable" or "infectious." In principle, at least, these are now well understood and capable of being scientifically dealt with. Their causes are known, as are also the sources in which they originate, and the vehicles by which they are transported. Their characteristic operations and effects are rapidly becoming familiar everyday facts. Their control, therefore, in theory at least, becomes easy and in a broad sense a problem of engineering, which subject has been defined as the scientific control and use of the forces and materials of nature for the benefit of man. So much, at least, of medical or sanitary engineering rests upon a sound scientific basis, and for this the term "sanitary science," as distinguished from "hygiene," may conveniently be

employed. If, hereafter, our knowledge of the constitutional diseases, and the ordinary conduct of individual life, comes to rest upon foundations equally sure, simple and scientific, either term — hygiene or sanitary science — may be dropped, for the two will be strictly synonymous. Until that time comes it will probably conduce to a just recognition of the real situation if we keep the term "hygiene" more as an end to be sought for than as something possessed, and endeavor by the constant extension of the boundaries of knowledge and the application of the principles of science, to enlarge the field of sanitary science until its boundaries become coterminous with those of hygiene. The mutual relations of hygiene, sanitary science, public hygiene and personal hygiene are dwelt upon at some length at the end of the first chapter, and to that place those are referred who care to pursue this subject further.

The present volume is the direct outgrowth of a course of lectures on Sanitary Science and the Public Health given for several years by the author to certain senior students—chiefly engineers, biologists, chemists and architects — of the Massachusetts Institute of Technology, and it has been prepared primarily for their use. It is believed, however, that a larger circle of students and some physicians, publicists and general readers may be glad to have access to the same material. If any apology is required for the occasional use of examples drawn from the author's personal experience, chiefly in Massachusetts, it may be said that these have been referred to, not because the author regards them as of paramount importance, but because he has preferred to deal as far as possible at first hand with matters within his own knowledge rather than to depend upon the digests or even the original reports of others.

It must not be forgotten that this volume deals with the principles, rather than the arts, of sanitation, nor that it is

based upon lectures given to beginners. It is intended to be no more than an elementary treatise on the subject; and while it is believed that it contains some new material, and some old material treated from new points of view, no special claim is made for originality either in substance or in method of presentation. The author has chiefly sought to bring together and to present in a simple and logical form those fundamental scientific principles on which the great practical arts of modern sanitation securely rest. The subject is so vast and touches human welfare at so many points that it has seemed wise to omit many things altogether, and to make in many cases only brief and summary statements where more extended treatment would have been easy and perhaps desirable. It is hoped, however, that clearness and accuracy have nowhere been sacrificed to mere condensation.

The author has prepared the present work in the earnest hope that it may find a useful place in sanitary education, both professional and popular, for he holds with Lord Derby that "sanitary instruction is even more important than sanitary legislation."

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PART I

HEALTH AND DISEASE

SANITARY SCIENCE AND THE PUBLIC HEALTH

CHAPTER I

ON HEALTH, OLD AGE AND DISEASE. A CLASSIFICATION OF DISEASES ACCORDING TO THEIR PLACE OF ORIGIN. DEFINITIONS

"The fundamental conception of the living body as a physical mechanism . . . is the distinctive feature of modern as contrasted with ancient physiology." — HUXLEY.

"To die of age, is a rare, singular and extraordinarie death." — MONTAIGNE.

§ 1. — *The Human Mechanism*

WE must endeavor to obtain at the outset clear ideas of what is meant by the words "health" and "disease," which, to physiologists at least, are terms of precise and definite meaning indicating actual states or conditions of the living body. A moment's consideration will show that it is essentially no more difficult to comprehend the idea of a general state or condition of a living body than a general state or condition of a lifeless body, such as a stone or a piece of iron or a watch or a locomotive.

Closely examined, the living body reveals itself as a machine or mechanism composed of parts (called organs) precisely as a watch does. Very much in the same sense that a watch is a time-piece a living body is a life-piece. If a watch appears to be in good order and running well,

we say that it is a good and normal time-piece. So also if the human body appears to be in good order and working well, we call it a normal or healthy body; but if it be out of order and not working well, we say that it is in a state of "disease," either temporary or permanent. In a word, health is the normal, and disease the abnormal, condition of the living mechanism. Nor is this a mere analogy or abstraction. To the biologist it calls up a picture — the picture of health or the picture of disease. For precisely as the experienced watchmaker carries in his mind's eye and can at any moment summon up a mental image of intricate, correlated and interdependent parts — springs, wheels, bearings — lying concealed within, but which, taken together and in a certain definite and orderly relation one to another, make up the works of a delicately adjusted chronometer in actual operation, and constitute a valuable time-keeper; so the physiologist, familiar with bones, muscles and nerves, with good red blood and beating heart, all coöperating to a common end, — the healthy, normal life of the organism, — can summon up at will the picture of normal, vigorous, almost superfluous vitality in some vascular life-keeper. And in one sense, hardly more wonderful to him is the pulsing, vibrant, living mechanism than to the jeweller the accurate chronometer of delicate adjustment. To the savage the watch would be incomprehensible and inexplicable. And so to others than physiologists the living body seems something altogether strange and wholly apart.

The student of sanitary science must take up the physiologist's point of view. He must look upon the living body as a mechanism; a mechanism of curious origin and history and of marvellous complexity; the most wonderful of all machines; one before which the wisest of men stands very much as does the savage before the chronometer, ignorant of its origin, ignorant of its ultimate construction, ignorant of its fate; but yet unlike the

savage because without superstition and without fear; knowing that the body is nevertheless a mechanism, subject to natural laws, and with all its parts coöperating to one end, — the life-keeping function of the whole. The living body is like a machine, also, in that it receives all its energy from without and is merely a transformer of energy; in that it is profoundly sensitive (as is a watch) to its environment — to heat, to cold, to mechanical injuries. This living machine may be well built or ill; of good timber or poor; it may be sound and flawless or defective in construction. These are accidents of birth or ancestry; effects of good feeding or bad, of normal living or abnormal.

§ 2. — *The Making of the Body. Youth and Maturity*

Unlike the watch, the living mechanism is not made, but grows. With the fusion of two unlike cells — ovum and spermatozoön — the life of the individual begins. Henceforward its increase in size, its acquirement of organs and tissues, its powers and properties, are due, not as in the making of a watch to the assembling and coöperation of parts already perfected, but to processes of its own, to cell growth, cell multiplication, cell differentiation — balanced, adjusted, directed and controlled chiefly from within. The first portion of this development takes place within the body of the parent, and is called intra-uterine or *embryonic life;* the second is a helpless state outside the body, but under parental care, the period of *infancy;* a third, somewhat less dependent but ill-defined, is the period of childhood and adolescence. These three periods — the periods of youth — ripen into adult life or maturity, and this passes on into old age. Only very rarely does the mechanism last longer than a century. Usually, long before this it has stopped in death, which may have marked the end of life at birth, or even long before it, in infancy,

in childhood, in maturity or in age. The period of growth and the period of decline — infancy and old age — appear to be the periods when death is least successfully resisted. As has been finely said: "In this last respect the two extremes of life resemble one another. The freshly lighted taper and that which is burnt down to the socket are both easily extinguished by the slightest puff of wind." [1]

§ 3. — *Old Age*

Finally the living mechanism may wear out — it must wear out. No machine, however perfect, can run or be run forever. However smooth its bearings, however perfect its adjustments, dust and friction, and wear and tear, do their work, and in time the machine becomes old. So, also, is it with the human mechanism. No matter how well cared for, or how cleverly managed, old age finally creeps over it; the rust of rheumatism gathers in its joints; its bearings grow eccentric; its movements irregular and halting; until by and by something breaks, and death stops the whole machinery. Death is the final stoppage of the living mechanism. But while theoretically this comes only when all parts are worn out, and as the simple, natural cessation of function from sheer and general debility of each and every organ, it does not in fact come very often in this way. The machine breaks down; it does not wear out. Some organ or part gives out comparatively early, and by failure to do its part destroys the whole.

Facts like these may or may not have inspired the author of the "One-Hoss Shay," who, in his famous poem has described the building of the body; its defects of constitution and construction; the ordinary causes of its death; and, finally, the theoretic possibility of so making a living body that it shall die at last only because it is worn out,

[1] P. H. Pye-Smith, "Lumleian Lectures," London, 1892.

namely, from old age. In the person of the deacon the Autocrat, himself a physiologist, has, consciously or unconsciously, stated the case as follows: —

"Now in building of chaises, I tell you what,
There is always *somewhere* a weakest spot, —
In hub, tire, felloe, in spring or thill,
In panel, or cross-bar, or floor, or sill,
In screw, bolt, thoroughbrace, — lurking still,
Find it somewhere you must and will, —
Above or below, or within or without, —
And that's the reason, beyond a doubt,
A chaise *breaks down*, but doesn't *wear out*."

His remedy for this unfortunate state of things was, —

"only jest
T' make that place uz strong uz the rest."

Accordingly the deacon proceeded to build his masterpiece in such a way that —

"The wheels were just as strong as the thills,
And the floor was just as strong as the sills,
And the panels just as strong as the floor,
And the whippletree neither less nor more,
And the back cross-bar as strong as the fore,
And spring, and axle and hub *encore*," —

with the result that after a whole century of life though there were indeed

. . . "traces of age in the one-hoss shay,
A general flavor of mild decay,"

there was

"nothing local as one may say!"

And when the end came from sheer old age, —

. . . "it went to pieces all at once —
All at once, and nothing first —
Just as bubbles do when they burst."

Such is old age: the low-burning flame, which flickers and finally goes out; the ripened fruit, which drops heavily to earth; the old mechanism, which after long years of

service finally refuses to work, simply because it is worn out. All this is the natural and ordinary course of life. With this sanitary science has but little to do except to exercise a wholesome supervision and watchfulness and to provide the most favorable environment possible. With ordinary breakdowns from defects in the machine itself, in its construction, or its operation, sanitary science has also little if anything to do. Good stock comes by inheritance not by manufacture, as truly in men as in timber. Men do not gather grapes from thorns or figs from thistles. Neither do strong constitutions, as a rule, spring from weak ancestors or good lungs from tuberculous parentage.

§ 4. — *Death and its Causes*

Life is the period of activity of the vital mechanism. Death marks the final stoppage of that machinery. Life is a perpetual struggle of the organism with its environment. Death marks its final and unconditional surrender. In the higher forms of life death is the natural and inevitable end of life. Old age marks the approach of death and is not less natural and inevitable. Doubtless the principal cause of death should be old age, the natural maturity of the organism, the gradual and irreparable wearing out of the vital machinery. Yet if we turn to any work on vital statistics, such as a Registration Report, we find far more prominence given to other factors of mortality. In the enumeration of the causes of death in the Registration Report of Massachusetts, for example, there are laid down five general classes of causes, namely, as follows: —

I.	Zymotic Diseases . .	(Fevers, etc.)
II.	Constitutional Diseases .	(Gout, Cancer, Scrofula, Dropsy, etc.)
III.	Local Diseases . .	(Apoplexy, Heart Disease, etc.)
IV.	Developmental Diseases	(Teething, Old Age, etc.)
V.	Violence	(Drowning, Murder, Accidents, etc.)

If we look for old age, we find it under Class IV counted as a disease along with teething, — an equally normal process of the living organism. The great variety in the causes of death may be still more clearly seen by counting the subdivisions of the foregoing classes which are in number as follows in the Registration Report referred to: —

I.	32	Causes of Death
II.	10	" " "
III.	48	" " "
IV.	10	" " "
V.	14	" " "

It will be seen that Classes I–IV include seven-eighths of all the recognized causes of death. In other words, various forms of disease constitute seven-eighths of all the recognized causes of death, and it only requires a somewhat closer examination of mortality tables to show that old age is assigned as the cause of death in a very small percentage of cases.

§ 5. — *Disease, not Old Age, the Principal Agent of Death*

From the previous paragraph it is clear that disease is the cause of death most often assigned by physicians in filling out their official certificates; while old age, which may be considered the most natural cause, is comparatively rare. But this is much more apparent than real, since it often happens that disease would have been powerless to cause death if the vital machinery had not already been weakened by age. To what extent death is really due to age it is, and always must be, impossible to say. The truth appears to be that many deaths occur under, and are attributed to, disease which would not have been able to cause death had the victim been either older or younger; while, on the other hand, death would not have occurred when it did if disease had been absent.

There occurred in Massachusetts, in 1890, 45,108 deaths

from specified causes, and all but 1814, or four per cent, were assigned by the physicians reporting them to the effect of some disease. Disease, violence and old age, then, would appear to be the principal causes of death; disease causing about ninety-two per cent, violence four per cent, and old age four per cent, and if disease is thus in reality, as it is apparently, the principal agent of death, it is obviously to the prevention of disease that sanitary science must address itself. Hence has arisen its synonym "preventive medicine," *i.e.* such action as shall prevent the ravages of disease.

§ 6. — *Another Classification of the Causes of Death*

A simpler, and for our purpose more helpful, view of the causes of death is one which seeks to classify them roughly according to their apparent place of origin, simply regarding them as either —

(*a*) *Intrinsic* causes, or arising within the body proper, or

(*b*) *Extrinsic* causes, arising outside the body or acting upon it from without.

From this standpoint diseases may be regarded as due either to defects in the constitution or construction of the vital mechanism, or else to external unfavorable influences acting upon it. From the point of view of origin or causation, all diseases may be divided into two classes, viz.: —

I. *Constitutional*, or
II. *Environmental*

This classification, while open to many objections, is of the highest value to the physiologist and the sanitarian, for it brings the former face to face with intrinsic, structural, or organic defects in the mechanism, while the attention of the latter is concentrated upon those abnormal external influences which act unfavorably upon the organism, and which he must seek, and may be able, to remove.

A count of the principal causes of death laid down in the Registration Report of Massachusetts shows that on this basis, and approximately speaking, there are there given —

(1) Extrinsic or environmental causes of death 56
(2) Intrinsic or constitutional " " " 58

In other words, one-half of the principal assigned causes of death, from this point of view, may be said to proceed from within the organism and one-half from without; one-half would therefore lie within the domain of the physiologist and one-half within the field of the sanitarian. It will be found instructive to carry this line of thought considerably further, as in the next following sections, carefully keeping in mind the fact that many so-called intrinsic causes probably have in reality, though perhaps only remotely, an extrinsic source or origin.

"Any arrangement of diseases is valuable so far as it helps the memory to retain useful facts; any arrangement is useless or mischievous if it pretend to be a universal or 'natural' or 'scientific' system. Diseases are not natural objects; they are physiological states, which we sometimes define by their cause, as plumbism [lead-poisoning] and scabies [itch]; sometimes by their histology, as sclerosis of the spinal cord and epithelial cancer of the lip; sometimes by their constancy in transmission, as measles and typhus; and sometimes by more or less constant concurrence of symptoms, as chorea and epilepsy."[1]

§ 7. — *Intrinsic or Structural Defects of the Vital Machinery; Constitutional Diseases*

The human body is a wonderful machine, an admirable piece of mechanism. Like other complicated machines, it has a definite structure and interdependent and reciprocating parts. These are naturally adjusted to the per-

[1] Pye-Smith, "Diseases of the Skin," London, 1893.

formance of certain duties or functions, and a failure of one part may involve the failure of all other parts and thus of the entire vital apparatus. If, for example, the heart is defective and fails to do its duty, the circulation is affected unfavorably and the whole body suffers. It needs no further argument or illustration to show that a structural flaw or defect in the living machine may mean disaster and death, however favorable all external conditions may be. A condition of the blood, or a roughness upon the valves of the heart, which shall produce a clot, or a weakening of an arterial wall in the brain which shall finally produce cerebral hemorrhage or cause apoplexy, is an intrinsic or structural defect which may not be directly attributable to any unfavorable external condition. It may be a flaw in the machine, an intrinsic and perhaps inherited defect of structure; and, if so, it is remediable only by fundamental changes in organization which sanitary science cannot hope to establish, unless after many generations and by steps which are at present quite beyond its reach. Diseases of this class are diseases of construction, *i.e.* "intrinsic" or "constitutional." They belong as yet in the field of the biologist, the physiologist and the hygienist rather than that of the sanitarian; to personal hygiene, rather than public hygiene or sanitary science.

§ 8.—*Extrinsic or External Interferences with the Vital Machinery; Environmental Diseases*

The human body is subject—sensitive, even—to external conditions: cold or heat, fire or water, may so act upon the human body as to produce death by freezing, burning, or drowning. Forces, such as gravity or electricity, may be causes of death by falling, crushing or execution. These and similar causes are clearly extrinsic or environmental, and come under the head of accident or violence —unless we except suicide as perhaps due to constitu-

tional peculiarities. Some diseases have already been spoken of as constitutional or intrinsic, but many diseases do not come under this head. The common expression which describes an infectious disease as an "attack" is noteworthy as indicating the popular recognition of the fact that disease often has its source outside of the body. It is now believed that many diseases originate exclusively from unfavorable environmental influences, and since the celebrated discovery of 1839 of the vegetable nature of the cause of *favus* (honeycomb of the scalp), it has been found that not a few diseases are due to parasites, which invade the organism and interfere with its normal working.

§ 9. — *The Prevention of Constitutional Diseases the Special Function of Personal Hygiene*

If diseases due to defects or flaws in the vital machinery are to be avoided, this is obviously to be done only by improving and perfecting the apparatus, which is a comparatively slow and difficult matter. To make a family of weak constitution strong, is to reconstitute its entire physical basis; and if this can be done at all, it may be only after generations shall have come and gone. It must be done by careful living and good feeding, wise intermarriage and severe natural selection. To ward off adventitious disease is, in these cases, not enough. The whole structure must be made over. Sanitation alone cannot hope to effect these changes. They must come from scientific hygiene carefully applied throughout long generations.

§ 10. — *Extrinsic or Environmental Diseases mainly Preventable and therefore within the Scope of Sanitation*

Diseases which arise from some invasion of the organism may possibly be warded off. As they virtually proceed

from the environment which, in theory at least, is under our control, they may be prevented. With such diseases the sanitary science of to-day is chiefly concerned. Sanitation has stamped out small-pox in many civilized communities. It is seeking to-day, with more or less success, to do away with typhoid fever. It boldly attacks epidemics of diphtheria and scarlet fever, and has recently sought to control tuberculosis and malaria. There can be no question that it has already won signal victories, and that its practitioners may reasonably hope for fresh laurels in the near future.

§ 11. — *The Prevention of Premature Death the Principal Function of Hygiene and Sanitary Science*

From what has been said above it would appear that disease is the principal agent of death. But it must be kept in mind that disease (except in infants) is often facilitated in its work by age or enfeeblement, which gives it a foothold and incapacitates the organism for resisting its activity. Physiologists and physicians recognize differences of condition in which the body seems to possess great powers of resistance or endurance, or only small powers (p. 71). In this way it often happens that a structural or constitutional enfeeblement exposes the organism to the invasion of environmental disease; as, for example, a low condition of vitality is generally believed to increase enormously the susceptibility to attacks of typhoid fever; and as soldiers, enfeebled by long marches or bad feeding, appear to suffer unduly from certain camp diseases.

A little reflection will show that death, as a rule, comes prematurely. Old age, the only theoretically normal and natural cause of death, is very rarely the one and only cause. Poor timber or poor materials or poor construction of the living machinery, alone or together making up a poor "constitution," or else violence, poison, parasites or

unfavorable elements in the environment, usually bring on disease and death long before the appointed threescore years and ten, or the rarer fourscore years. Many die before they are born; more before one year of life is over; others under five years, ten or twenty. A few live on for thirty, forty or fifty years; but for the great majority death comes before old age, before "the lean and slipper'd pantaloon." All this means that death is oftenest premature; and *the principal function of sanitation and of the applications of hygiene in general is the prevention of premature death:* Hygiene in its widest sense goes further, and seeks to elevate or maintain at a high level the standard of normal living.

§ 12. — *Hygiene and Sanitary Science*

Sanitary science is the science of health. It is commonly held to be, and commonly it is, much the same thing as hygiene. Sciences and arts, however, like living organisms, grow, differentiate and divide, and hygiene is no exception to the rule. The wonderful developments which have taken place within the last half century in our knowledge of the causes of disease, and especially those diseases proceeding from the environment, together with the corresponding advancement in our arts for their prevention or control, — the sanitary arts, — have brought about a differentiation of hygiene such that one portion of it now deals naturally and mainly with the environment of man, while another portion deals naturally and mainly with man himself.

As the environment is usually shared in common by many persons, that branch of hygiene which deals mainly with the environment may conveniently be called "public" hygiene; while the remainder, dealing as it does chiefly with the individual, may properly be designated "personal" hygiene. Underlying both personal and public hygiene

there are certain fundamental principles of the causation and prevention of disease which are absolutely essential to all sound practice of the sanitary arts. These, steadily growing in number and importance as the years go by, constitute the firm foundation on which both the theory and the practice of personal and public hygiene rest. Moreover, because they are founded largely upon experiment, and are in harmony with established laws of nature, they may be said to constitute the beginnings, at least, of a sanitary "science." Furthermore, inasmuch as the environment is not only more accessible for treatment than the individual, but also far more under our influence and control, it has naturally come to pass that sanitary science consists very largely of principles derived from, and applicable to, problems relating to the environment rather than the individual. Hence it happens that it is at present most often and most naturally associated with public hygiene or the public health rather than with general hygiene or with personal hygiene, or the health of the individual.

The whole subject of proper food and clothing, for example, pertains to general or personal hygiene; but sanitary science is more especially concerned with infected food and clothing. Whether the citizens of Boston or Paris dress warmly enough, or too warmly; whether cotton, linen or wool is, on the whole, the most suitable for the climate of New York or London at all seasons or at any season — these are questions of general or of personal hygiene; but the question of infection by means of clothing made in the den of the sweater; the question of the disinfection of Egyptian rags arriving in the harbor of London or Boston; the conveyance of disease germs by the clothing of persons dead of small-pox or scarlet fever — these are the peculiar property of sanitary science and the public health. To sanitary science and the public health belong also questions of polluted water, polluted

milk and polluted air; questions concerning the origin, dangers and disposal of sewage; questions relating to dust and disease and to the natural history of epidemics. The practice of sanitary science is founded, as applied science must always be founded, upon a basis of established truth. Upon this sure basis we may construct a framework of philosophical explanation, or theory, by the aid of which we may hope to make or measure new discoveries. Though often unrecognized, some such working theory lies at the bottom of all sanitary endeavor. It has underlain the prayers and incantations of savages; it underlies all quarantine regulations; it is at the foundation of all sanitary authority.

The past fifty years have witnessed vast additions to our store of established truth, and vast changes in our stock of theory, underlying all the application of sanitary science. These additions we owe almost wholly to one simple mechanical discovery in the domain of physics — the discovery how to make an achromatic microscope objective. This discovery so facilitated and stimulated the use of the microscope that it has revolutionized ideas of the causation of disease; has established physiology upon a broad and firm foundation; and has created new sciences of immense importance, such as general biology, pathology and bacteriology.

§ 13. — *Definitions*

As a recapitulation of the foregoing paragraphs the following definitions may be found useful for beginners, although like most definitions they are only approximately correct and must not be taken too literally.

HYGIENE

Hygiene (*general hygiene*) *is the whole science and art of the conservation and promotion of health both in indi-*

viduals and in communities. It has for its function the prevention of premature death and the promotion of normal life, health and happiness both directly by conservation and reënforcement of organisms and groups of organisms, and indirectly by the elimination or amelioration of unfavorable environmental conditions both local and general.

The field of hygiene is immense, for it includes not only all of sanitary science and the sanitary arts, but a large part of physiology and even of biology as well. It includes not only questions of water supply, milk supply and sewerage, but also much of climatology, foods and feeding, clothing, heating, lighting, ventilation, vaccination, scavenging, the personal care of the body, work and overwork, sleep, rest, fatigue, exercise, play, sports, noise, crowding and overcrowding, and other subjects too numerous to mention but comprised in part under the heads of public hygiene and personal hygiene, municipal sanitation, school sanitation, household sanitation, offensive trades, unwholesome or dangerous trades, quarantine, toxicology, etc.

PUBLIC HYGIENE

Public hygiene is the science and the art of the conservation and promotion of the public health. It has for its function the prevention of premature death and the promotion of normal life, health and happiness in communities chiefly by the elimination or amelioration of unfavorable environmental conditions common to many persons or communities either at one time or at different times.

It includes especially hygienic problems common to groups or communities, such as camps, villages, towns and cities, *e.g.* water supplies, drainage, milk supplies, ice supplies, the control of infectious diseases, heating, lighting, ventilation, school sanitation, municipal sanitation, and the like. The establishment of municipal gymnasia in many cities shows that the necessity of muscular exercise under the conditions of urban life is becoming a ques-

tion of public as it has long been of personal hygiene. There is undoubtedly a natural tendency for all questions of personal hygiene to become more and more problems of public hygiene.

PERSONAL HYGIENE

Personal hygiene is the science and art of the conservation and promotion of personal health, and has for its function the prevention of premature death and the promotion of normal individual life, health and happiness chiefly by direct conservation and reënforcement of that physical mechanism which we call the human body.

It includes especially problems relating to proper foods and feeding of the individual, his sleep and rest, his work and fatigue, his muscular exercise, stimulants and narcotics, the care of the eyes, the ears, the teeth, the bowels, the hair and other organs, clothing for special conditions, etc.

SANITARY SCIENCE (HYGIOLOGY)

Sanitary science (hygiology) is that body of hygienic or sanitary knowledge which having been sufficiently and critically examined has been found so far as tested to be invariably true. Its phenomena are natural phenomena, its laws are natural laws, its principles are scientific principles.

It includes those hygienic facts and theories which have been so thoroughly verified by repeated observation and experiment as to have become worthy to rank as scientific principles. A good example of such a body of fact and theory is that which underlies, and is correlated by, the germ theory of infectious disease, which is described in the next chapter. Like some other sciences, while largely inductive it is also in part deductive.

THE SANITARY ARTS

The sanitary arts are those methods and processes by which the applications of the principles of sanitary science or hygiene are effected.

They include the practical processes involved in all sanitary engineering and architecture, *e.g.* in water-supply, sewerage, ventilation and heating, municipal sanitation, school hygiene, etc. Among the most important are the construction and operation of reservoirs, filters, conduits, sewers, sewage fields and hygienic schoolhouses, the cultivation and preparation of vaccine, the manufacture of antitoxines, the inspection of foods and drugs, the examination of drinking waters, the disposal of garbage and refuse, the construction and maintenance of streets, the abatement of nuisances, the control of dangerous or offensive trades, etc.

CHAPTER II

ON ÆTIOLOGY OR THE CAUSES OF DISEASE. ANCIENT AND MODERN THEORIES. THE ZYMOTIC (FERMENT) OR GERM THEORY OF INFECTIOUS DISEASE

"How far the power of spirits and devils doth extend and whether they can cause this or any other disease, is a serious question and worthy to be considered." — BURTON'S "Anatomy of Melancholy."

"Diseases and death are the consequences and effects of sin; this is the idea which we have of them from Scripture."

— CRUDEN'S "Concordance."

"Diseases have been generally considered as the inevitable inflictions of Providence." — MALTHUS.

"Diseases . . . will perhaps be never properly understood without an insight into the doctrine of fermentations." — BOYLE.

"Side by side with these . . . has run the germ theory of epidemic disease. The notion was expressed by Kircher, and favored by Linnæus, that epidemic diseases may be due to germs which . . . enter the body, and produce disturbance by the development within the body of parasitic life." — TYNDALL.

"Moreover, if inquiry into the origin and conditions of disease helps treatment, it is indispensable for the still better art of prevention. That depends entirely upon the extent of our knowledge of ætiology."

— PYE-SMITH.

THE sanitarian must have sound working theories of disease. If he is to maintain and promote the public health, he must be familiar with the causes of disease and the avenues along which they travel. In order to prevent disease he must know, if possible, precisely what disease is. To-day all civilized and scientific persons regard disease, as has been indicated in the preceding chapter, as a state or condition of disturbance or abnor-

mality[1] which the body has unfortunately assumed or been placed in. Savage and uncivilized people, on the contrary, and the unscientific civilized, are apt to look upon disease as an entity, something to be pacified, cajoled or cast out. Very often this entity is personified, and illustrates that subjective characteristic which is so marked a feature of primitive culture.

§ 1. — *The Demonic Theory of Disease*[2]

The earliest theories of disease with which we are acquainted are found among savage races, which naturally interpret fever, sickness, pain, madness and hysteria as due to the temporary or prolonged occupancy of the affected body by an evil spirit or demon. This is called the *Demonic Theory*. The same subjective, anthropomorphic method of thought which sees in the sun, not a huge sphere of burning matter giving light and life to other worlds, but Apollo, a god, driving his chariot of fire daily across the sky; or fills the woods with fauns and satyrs, and the streams with nymphs and naiads, naturally looks for the causes of disease in human or inhuman forms distorted and misshapen according to the fancy, but gifted with human cunning and more than human malignity.[3]

[1] "Disease is a state of a living organism . . . the disease itself is a perturbation. . . ." — ALLBUTT, "Syst. Med.," I. xxiv.

[2] For the substance, and to a great extent the form, of this entire section the author is indebted to various writings of that eminent authority on primitive culture, Professor E. B. Tylor.

[3] "Among races of low culture, the conception of a ghost soul being made to account for the phenomena of life readily leads to a corresponding theory of morbid states of body and mind. As the man's proper soul causes the functions of normal life by its presence, while its more or less continued absence induces sleep, trance, and at last death, so the abnormal phenomena of disease have a sufficient explanation at hand, in the idea that some other soul or soul-like spirit is acting on or has entered the patient. Among the cases which most strongly suggest this, are: first, such derangements as hysteria, epilepsy, and madness, where the raving and convulsions seem to

The demonic theory regards disease as a supernatural being or entity, not primarily as a process or condition,

by-standers like the acts of some other being in possession of the patient's body, and even the patient is apt to think so when he 'comes to himself'; and second, internal diseases where severe pain or wasting away may be ascribed to some unseen being wounding or gnawing within. This applicability of demoniacal possession as a theory to explain disease in general is best proved by the fact that it is so often thus applied by savage races. Especially, reasoning out the matter in similar ways, rude tribes in different countries have repeatedly arrived at the conclusion that diseases are caused by the surviving souls or ghosts of the dead who appear to the living in dreams and visions, thus proving at once their existence after death and their continued concern with mankind. This notion being once set on foot it becomes easy to the savage mind to identify the particular spirit, as when the Tasmanian ascribes a gnawing disease to his having unwittingly pronounced the name of a dead man, who, thus summoned, has crept into his body and is consuming his liver; or when the sick Zulu believes that some dead ancestor he sees in a dream has caused his ailment, wanting to be propitiated with a sacrifice of an ox; or when the Samoan persuades himself that the ancestral souls, who on occasion reveal themselves by talking through the voices of living members of the family, are the same beings who will take up their abode in the heads or stomachs of living men and cause their illness and death. . . . In many, perhaps in most, cases, however, the disease demon is not specially described as a human ghost; for instance, some Malay tribes in their simple theory of diseases are content to say that one kind of demon causes small-pox, another brings on swellings, and so on. . . . The savage theory of demoniacal-possession has for its natural result the practice of exorcism or banishment of the spirit as the regular means of cure, as where, to select these from hundreds of instances, the Antilles Indians in Columbus's time went through the pretence of pulling the disease off the patient and blowing it away, bidding it begone to the mountain or the sea; or where the Patagonians, till lately, believing every sick person to be possessed by an evil demon, drove it away by beating at the bed's head a drum painted with figures of devils.

"That such modern savage notions fairly represent the doctrines of disease-possession in the ancient world is proved by the records of the earliest civilized nations. The very charms still exist by which the ancient Egyptians resisted the attacks of the wicked souls, who, become demons, entered the bodies of men to torment them with diseases and drive them to furious madness. The doctrine of disease among the ancient Babylonians was that the swarming spirits of the air entered man's body, and it was the exorcist's duty to expel by incantations 'the noxious neck-spirit,' 'the burning spirit of the entrails which devours the man,' and to make the piercing pains in the head to fly away 'like grasshoppers' into the sky. . . . No record shows the ancient theory more clearly than the New Testament from the explicit way in which the

and the diseased condition is the result of the influence of some entity foreign to the patient, to something acting

symptoms of the various affections are described, culminating in the patient declaring the name of his possessing demon, and answering in his person when addressed. The similarity of the symptoms with those which in barbarous countries are still accounted for in the ancient way may be seen from such statements as the following, by a well-known missionary (Rev. J. L. Wilson, 'Western Africa,' page 207): 'Demoniacal possessions are common, and the feats performed by those who are supposed to be under such influence are certainly not unlike those described in the New Testament. Frantic gestures, convulsions, foaming at the mouth, feats of supernatural strength, furious ravings, bodily lacerations, gnashing of teeth, and other things of a similar character may be witnessed in both of the cases.' Among the early Christians the demoniacs or energumens formed a special class under the control of a clerical order of exorcists, and a mass of evidence drawn from such writers as Cyril, Tertullian, Chrysostom, and Minutius Felix shows that the symptoms of those possessed were such as modern physicians would class under hysteria, epilepsy, lunacy, etc. . . . Some theologians, while in deference to advanced medical knowledge they abandon the primitive theory of demons causing such diseases in our own time, place themselves in an embarrassing position by maintaining, on the supposed sanction of Scripture, that the same symptoms were really caused by demoniacal possession in the first century. . . . For our times this seems too like a discussion whether the earth was really flat in the ages when it was believed so, but became round since astronomers provided a different explanation of the same phenomena. It is more profitable to notice how gradual the change of opinion has been from the doctrine of demon-possession to the scientific theory of disease, and how largely the older view still survives in the world. Not only in savage districts, but in countries whose native civilization is below the European level, such as India and China, the curious observer may still see the exorcist expel the malignant ghost or demon from the patient afflicted with fever, dizziness, frenzy, or any accountable ailment. . . . The unbroken continuance of the belief in mediæval Europe may be gathered from various works. . . . Even in the eighteenth century was published with ecclesiastical approval a regular exorcist's manual, the 'Fustis et Flagellum Dœmonum,' Auctore R. P. F. Hieronimo Mengo (1727), which among its curious contents gives instructions how to get the better of those cunning demons who hide in the bodies of men and vex them with diseases, and which are apt, when expelled, to take refuge in the patient's hair. The gradual shifting of opinion is marked by the attempt to reconcile the older demonology with the newer medicine. The argument, which appears among the early Christian fathers, is worked out most elaborately in that curious museum of demonology, the 'Disquisitiones Magicæ' of Martin Delrio, published as late as 1720. While inveighing against those physicians who maintain that all diseases have natural causes, this learned Jesuit

from or coming from the environment. Of any disease arising from within, or due to any intrinsic or mechanical defect or derangement of an apparatus — such as faulty materials or construction — the savage has no conception. This idea requires anatomical information and the power to reflect from the merely objective point of view; in other words, the modern mechanical and scientific attitude of mind, the objective rather than the subjective capacity. Even here, however, the cure was logically applied. Savage therapeutics accurately followed savage pathology. If the disease were due to the possession of the patient by a demon or demons, nothing could be more logical or better medical practice than to seek somehow to cast them out. Exhortations, drums, or anything likely to influence the demon constituted a proper *materia medica*. Most

admits that men may be dumb, epileptic, or lunatic without being obsessed; but what the demons do is that, finding the dispositions of epileptics suitable, they insinuate themselves into them; also they attack lunatics, especially at full moon, when their brains are full of humors, or they introduce diseases by stirring up the black bile, sending blacks into the brain and cells of the nerves, and setting obstructions in the ears and eyes to cause deafness and blindness. Looking at the date of this celebrated work, we cannot wonder that in benighted districts of Europe the old diabolical possession and its accompanying exorcism may still now and then be met with, as in 1861 at Morzine in Savoy. The London *Times*, in November, 1876, contained an account of the casting out of devils by a priest in the Church of the Holy Spirit in Barcelona, during the preceding month. On one occasion, the patient, a young woman of seventeen or eighteen, lay on the floor before the altar, writhing in convulsions, with distorted features and foaming at the mouth, while the priest carried on a dialogue with the devil, whom he addressed by the name of Rusbel, the fiend's answers being of course spoken by the voice of the frantic girl herself. At last a number of demons were supposed to come out of the patient's body, and such scenes were repeated for days in the presence of many spectators till a riot arose, and the civil authorities, intervening, put a stop to the whole affair. One of the last notable cases of this kind in England was that of George Lukins of Yatton, a knavish epileptic, out of whom seven devils were exorcised by seven clergymen, at the Temple Church at Bristol, on June 13, 1788.' — TYLOR.

. . . . "Thy demon, that's thy spirit that keeps thee."

— "Antony and Cleopatra."

effective of all would be the voice of a master who should command their obedience and compel them to come out.

It was even possible upon the demonic theory, crude and childish as it was, to have a legitimate "preventive medicine." "The very charms still exist by which the ancient Egyptians resisted the attacks of the wicked souls, who, become demons, entered the bodies of men to torment them with disease and drive them to furious madness." And we all know of survivals even to-day in the charms and amulets which are supposed to resist bad luck, and the more material horseshoe, rabbit's foot, horse-chestnut in the trousers pocket, etc., which shall ward off witches or disease from us or from our habitations.

§ 2.—*The Theory of the Four Humors*

Long before the period of the highest development of Greek civilization, the primitive or demonic theory of disease had ceased to satisfy the minds of cultivated men. Many traces of it indeed remain in the Homeric time; but with the arrival of the age of Pericles we have as his contemporary Hippocrates, already called "the Great," and ever since known as the "Father of Medicine." And now, apparently, for the first time, we find "a clear recognition of disease as being equally with life a process governed by what we should now call natural laws. . . . The actual science of the Hippocratic school was of course very limited. In anatomy and physiology little advance has been made, and so of pathology in the sense of an explanation of morbid processes or knowledge of diseased structures there could be very little. . . . The dominating theory of disease was the humoral, which has never since ceased to influence medical thought and practice. According to this celebrated theory, the body contains four humors,—blood, phlegm, yellow bile, and black bile,—a right proportion and mixture of which constitute

health; improper proportion and irregular distribution, disease. It is doubtful whether the treatise in which this theory is fully expounded is as old as Hippocrates himself; but it was regarded as a Hippocratic doctrine, and when taken up and expanded by Galen, its terms not only became the common property of the profession, but passed into general literature and common language. Another Hippocratic doctrine, the influence of which is fortunately not even yet exhausted, is that of the healing power of nature."[1] Much of the language of this famous theory still lingers, as when we speak of a "bilious" condition, a "sanguine," "phlegmatic," or "melancholic" (black bile) temperament. It had the high merit under Hippocrates of fixing attention upon natural rather than supernatural causes, upon the patient rather than demons.[2]

§ 3. — *Roman, Arabian and Mediæval Theories of Disease*

We need not follow in detail the shifting opinions of mankind as to the true causes of disease between the time of Hippocrates (500 B.C.) and that of Sydenham. In the decline of Greek culture and the Alexandrian period no new ideas of importance were successfully advanced or long maintained. The theory of the four humors, with various modifications and under various forms, prevailed, and even in the hands of Galen during the Roman period, though expanded and highly elaborated so that it became the standard authority for many centuries, remained essentially the same. During the Dark Ages no important new

[1] J. F. Payne, M.D., on the "History of Medicine," *Encyclopædia Britannica*, 9th ed., Vol. XVII, p. 800.

[2] "The four Galenical humors, viz., the blood which took its origin in the liver, the phlegm secreted by the pituitary gland, the bile by the gall, and the black bile by the spleen. From the mixture of these humors arose the four natural 'temperaments': sanguine, in which the blood was predominant; phlegmatic or pituitous; bilious or choleric; atrabilious or melancholic; and from the ill-mixture of these ingredients resulted dyscrasia and new morbid humors, such as produced scurvy, scrofula and gout." — PYE-SMITH.

ideas were introduced into Europe by the Arabian physicians, Avicenna and Rhazes; for these authors worked largely upon the foundations laid by Hippocrates and Galen, and their theories need not detain us. The period of scholasticism also yielded nothing in the theory of disease beyond the four humors, but only endless commentaries on Hippocrates and Galen similar in character to those in philosophy upon Aristotle. Even for some time after the revival of learning and the splendid period of the Renaissance, this very revival being in the hands of "medical humanists" led to a renewed respect for ancient authority, and more than ever Hippocrates and Galen were regarded as authorities while the theory of the four humors naturally held full sway. With Paracelsus (1480–1541), however, emphatic doubts began to be boldly expressed as to the sufficiency of the ancient theories. The study of anatomy in Italy in the sixteenth century under Vesalius, Fallopius, Fabricus and many others, followed as it was early in the seventeenth by Harvey's marvellous discovery of the circulation of the blood, together with the general progress of knowledge, finally raised grave doubts in the best minds as to the true causes of disease, doubts which were powerfully supported by the occurrence in Europe in the fifteenth and sixteenth centuries of certain highly destructive epidemic diseases, some of them hitherto unknown and all quite inexplicable on the theory of the four humors. Meantime there arose two schools, called respectively the "iatro-physical" and "iatro-chemical," the former basing itself on physiology and mechanical explanations of disease, the latter on chemical or fermentative processes. "The intestine movement of particles," or "fermentation," was the essence of the latter, the application of physics and mechanics to the body that of the former. The name of Sylvius (1614–1672) is widely known in connection with the iatro-chemical school. These schools, however, were compelled to

struggle not only each with the other but both with the ancient (Hippocratic) doctrines.

§ 4. — *The Theory of Sydenham*

Thomas Sydenham (1644–1689), who has been called "the English Hippocrates," held as "his main avowed principle to do without hypothesis and study the actual diseases in an unbiassed manner." According to Sydenham, "a disease is nothing more than an effort of nature to restore the health of the patient by the elimination of the morbific matter." This full recognition of a *materies morbi* was a distinct advance, and foreshadows the time when the *materies morbi* would itself be regarded as specific in specific diseases. Sydenham appears to have recognized the fact that there are specific diseases, but to have fixed his attention rather on specific remedies than specific causes. The latter were not fully recognized until after Pasteur's classic researches on the specific microbic ferments of the diseases of wine and beer (1860–1864). After Thomas Sydenham (d. 1689) "the reign of canonical authority in medicine was at an end, though the dogmatic spirit long survived." The philosopher John Locke was a close friend of Sydenham, and the following quotation from one of Locke's letters is noteworthy: "You cannot imagine how far a little observation carefully made by a man not tied up to the four humors (Galen), or sal, sulphur, and mercury (Paracelsus), or to acid and alkali (Sylvius and Willis), which have of late prevailed, will carry a man in the curing of diseases though very stubborn and dangerous; and that with very little and common things, and almost no medicine at all."

§ 5. — *Theories of the Eighteenth Century*

The theories of disease in the eighteenth century reflect plainly the spirit of the times. On the one hand we find

views largely mechanical, physical and even astrological; and on the other, an opposing series more mystical, animistic and even spiritualistic. As natural successors to Hippocrates, Galen and Sydenham, we find Boerhaave, Haller and Morgagni, while opposed to them and as natural successors to Paracelsus, Hoffmann, Stahl (author of the Phlogiston theory in chemistry) and Hahnemann, — all more or less supernaturalists. The labors of Boerhaave, Haller and Morgagni served to establish upon a sure foundation our present essentially physical and mechanical views of constitutional disease (see pp. 11, 13), but shed very little light on the class of diseases now called "infections" (the fevers, etc.), which run a peculiar definite course and then disappear. But if these diseases baffled the naturalists of the eighteenth century, they were still less understood by the supernaturalists, of whom only one (Hahnemann) has succeeded in making himself felt in the nineteenth century by the perpetuation of a special "system" typical of the numerous "systems" of the eighteenth century.

§ 6. — *The Theory of Hahnemann*

"Hahnemann taught that disease is to be regarded as consisting especially of the symptoms of it as experienced and expressed by the patient, or as detected by the physician; in other words, that the chief symptoms, or the 'totality of the symptoms,' constitute the disease, and that disease is in no case caused by any material substance, but is only and always a peculiar, virtual, dynamic derangement of the health. 'Diseases' (Introduction to the 'Organon,' p. 17) 'will not cease to be spiritual dynamic derangements of our spiritual vital principle.' He says on page 3 of the 'Organon': 'For as far as the greatest number of diseases are of dynamic (spiritual) nature, their cause is therefore not perceptible to the senses;' and at page 18, referring to 'small-pox, a disease accompanied

by almost general suppuration,' he asks, 'Is it possible to entertain the idea of a material morbific matter being introduced into the blood?' He held that the psoric miasm, of which the itch is the outward and visible and comparatively harmless sign, was at the root of nearly all chronic disease, viz., of all chronic disease that was not due to syphilis or sycosis. . . . In all countries the doctrine of homœopathy is still without broad scientific recognition. . . . Hahnemann despised any deep study of disease, and theorized about it instead. Had he carefully inquired into the nature and natural history of disease as Hippocrates did, or as he himself inquired into the sensations of those who took infinitesimal doses, he would have done more for the world and his own reputation. Hahnemann was easily captivated by theories, but not very sound in his reasoning. But underlying all his system, as we have seen, was the idea that the causes of disease were impalpable, immaterial, spiritual, dynamic. And this great foundation was rotten. Modern medicine is doing some of its best work in showing the material and the visible character of the causes of many of the commonest diseases, and suggests this in many cases where it has not as yet been demonstrated. The cause of many diseases is shown to be a living germ or particle which can be discerned under the microscope, can be carried on a lancet or in a tube and inserted under the skin so as to produce its peculiar disease. . . . The causes of other diseases are often not merely visible under a microscope, but coarsely visible. We have been lately told, on high authority, that to produce certain forms of blood-poisoning one or two ounces at least of septic fluid are necessary. So with other forms of common disease. Alcohol does not destroy a liver or kidney in any dynamic or immaterial form, but in coarse quantities diligently repeated. The lead which paralyzes the painter's wrist is not a 'spiritual' thing. It is an accumulation of matter in the wrong place, and enters his

body in palpable quantities, and, what is more, can be recovered in similar quantities from his body. So with the uric acid or its salts in the blood of a person who has inherited his father's gout, and perhaps his port wine. It is not a 'spiritual' affair at all, but can be demonstrated chemically and under the microscope. The itch, to whose mysterious workings Hahnemann attributed two-thirds of the internal diseases of the body, including mania, cancer, gout, etc., is easily demonstrated to be dependent on an ugly crab-like insect, which can be destroyed in a few hours with sulphur, when there is an end both of it and of the itch."[1]

§ 7. — *Theories of the Nineteenth Century*

If the eighteenth century is noteworthy for its numerous "systems" of medical theory, the nineteenth is equally conspicuous for its distrust of "systems." This was due doubtless in part to the natural swing of the pendulum, but whatever the cause may have been, there was unquestionably, in the first part of the century, a wholesome distrust of all "systems" and a return to a study of the "natural history of disease," what has been called a "rational empiricism" serving as the basis of medical practice. This "return to nature" was powerfully stimulated and facilitated by the rapid contemporary development of physical science, and above all by the invention of the achromatic microscope objective between 1815 and 1830, so that the compound microscope, which had been so imperfect as to be almost useless, became about 1835 a powerful and altogether novel instrument. Almost immediately results of capital importance were reached, for in 1837 an Italian investigator, Bassi, announced the discovery that *muscardine*, a contagious disease of silkworms, previously not understood, is really due to a parasitic

[1] J. Grey Glover, M.D., on "Homœopathy," *Encyclopædia Britannica*, 9th ed., Vol. XII, pp. 126–129.

fungus. Two years later the still more startling discovery was made by Schoenlein that *favus*, or "honeycomb" of the human scalp, a disease[1] long known, but never understood, is really due to a parasitic fungus growing at the roots of the hair. At almost the same moment botanists discovered that yeast, hitherto regarded as a mysterious "ferment," is also a microscopic fungus; and the idea was boldly advanced that fermentation, which had long been held to be one of the causes of disease, was really due to microscopic fungi. The new microscope was also applied to the study of diseased tissue, and immediately disclosed ravages so coarse and obvious as to compel the idea of mechanical interference by palpable agents and to stimulate further search not only for the footprints of disease, but for the mysterious makers of those footprints. Meantime the applications of physics and chemistry to physiology by Johannes Müller and Wöhler, Marshall Hall and Liebig, were drawing attention to the mechanical and material aspects of living things and the modern conception of the body as a physical mechanism was becoming more firmly established. The pathologists likewise were making extraordinary progress in their explorations of the dead, and reporting constantly fresh examples of mechanical disturbance or interference, so that by the middle of the nineteenth century our theories of constitutional disease as largely due to poor timber or poor construction or mechanical breakdown were finally and probably forever established.

[1] This is a rare affection of the scalp and body due to the presence of a fungus *Achorion Schoenleinii*. The disease was recognized and named by Bateman and figured by Alibert. But it was not till 1839 that Schoenlein published in Müller's *Archiv* the discovery that the yellow crusts of Favus were neither pustular nor sebaceous, but were composed of the mycelia and conidia of a parasitic fungus. Ringworm of the Scalp was only proved to depend on the presence of a cryptogamic parasite in 1844 by Malmsen, the Swedish microscopist. He named the fungus *Trichophyton tonsurans*. —PYE-SMITH, *l.c.*

The case was different, however, with certain diseases, such as the fevers, which run a definite course and disappear. These remained still unexplained and inexplicable. But their solution also was at hand. The obscure phenomena of fermentation, as we have seen above, had been claimed to be closely connected with disease by the iatro-chemical school of the seventeenth century, and this suggestion had apparently never been wholly lost sight of, though it was eclipsed in the eighteenth century by the rapid development of physiology. Modern chemistry began to unfold itself toward the close of the eighteenth century, and by the end of the first half of the nineteenth century, when the achromatic objective had been perfected, fermentation had assumed in the hands of Liebig great popular importance.

In 1837 the first serious attempt was made to collect and study the vital statistics of England, and a classification of diseases became necessary. For this classification of the various causes of death the following was at first used: —

(1) Epidemic, endemic and contagious diseases.
(2) Sporadic diseases.
(3) Evident external causes.

Some years later we find instead the following classification: —

(1) Zymotic diseases.
(2) Constitutional diseases.
(3) Local diseases.
(4) Developmental diseases.
(5) Violence.

In other words, those diseases previously called "epidemic, endemic and contagious" are now described as "zymotic"; and upon this term we may dwell somewhat at length.

"The diseases of this class have been frequently spoken of as fermentations. . . . The property of communicating

their action, and affecting analogous transformations in other bodies, is as important as it is characteristic in these diseases, which it is proposed therefore to call, in this sense, 'zymotic.' A single word, such as 'zymotics,' is required to replace in composition the long periphrasis 'epidemic, endemic, and contagious diseases' with a new name, and a definition of the kind of pathological process which the name is intended to indicate. . . . The early medical observers have directed attention to the analogies zymotic diseases have with combustion, fermentation, putrefaction, and poisoning. These analogies have been, to a certain extent, confirmed by the researches of modern chemistry. . . . This class includes fever, small-pox, plague, influenza, cholera, and the other diseases which have the peculiar character of suddenly attacking great numbers of people at intervals in unfavorable sanitary conditions. The diseases of this class distinguish one country from another, one year from another; they have formed epochs in chronology, and, as Niebuhr has shown, have influenced not only the fate of cities, such as Athens and Florence, but of empires; they decimate armies, disable fleets; they take the lives of criminals that justice has not condemned; they redouble the dangers of crowded hospitals; they infest the habitations of the poor, and strike the artisan in his strength down from comfort into helpless poverty; they carry away the infant from the mother's breast, and the old man at the end of life; but their direst eruptions are excessively fatal to men in the prime and vigor of age. Pestilence and famine have always obtained the special attention of governments; and epidemical maladies have a special claim now to the attention of the statist, inasmuch as by prophylactic methods, of which vaccination is an example, and by hygienic arrangements, the ravages of epidemics may be greatly diminished. They are more than other diseases under public control, and may be diminished to a large extent by sanitary measures.

. . . New names are wanted to designate new groups of phenomena, and might perhaps be less equivocally designated by letters of the alphabet; but to assist the memory words have been employed which, by their etymology, will suggest the group. We do not, however, in any case accept the etymological sense as a definition or a description of the group of causes which a name designates. Thus, parts of the body undergo a specific transformation in the diseases of the first class, and they have been designated ZYMOTIC DISEASES (*zymotici*) in England, without any intention to imply that these diseases are fermentations."[1]

In spite of Dr. Farr's care not to assume close similarity between fermentations and zymotic disease,[2] the proof of such similarity was, even as he wrote, about to be brought forward by Pasteur.

§ 8. — *The Germ Theory of Fermentation*

Alcoholic fermentation had been generally regarded as a purely chemical or a physical process until in 1838 Cagniard de Latour and Schwann showed that the yeast which accompanies it is a living plant. Liebig met this discovery with scorn and ridiculed the idea that yeast was the cause rather than the consequence of fermentation in an article which Huxley has well called the most remarkable that ever appeared in a sober scientific journal. Nevertheless, though with many hindrances because of the powerful opposition of Liebig, it slowly became

[1] "Vital Statistics: A Memorial Volume of Selections from the Reports and Writings of Dr. William Farr," pp. 246, 249, 253. London, 1885.

[2] The reluctance of Dr. Farr to connect zymotic diseases with fermentations was not exceptional, and was probably due in part to the strenuous opposition of Liebig to that view. In 1863, Sir Robert Christison, in an "Address on Public Health" before the Association for the Encouragement of Social Science in Edinburgh, said of zymotic diseases, "They are so called from the Greek *zyma*, signifying ferment, on account of a rather fanciful resemblance between their origin and the process of fermentation."

clear that the germ theory of fermentation is true, and that live yeast is the real "ferment" of the alcoholic fermentation. This biological theory was thoroughly and finally established by Louis Pasteur between 1857 and 1863, and almost immediately led to the germ theory of disease through its extension by him to the diseases of beer and wine, which he traced to micro-organisms other than ordinary yeast invading the fermentable liquid and interfering with the usual alcoholic fermentation by producing undesirable fermentations of their own. At once it became clear to Pasteur (and soon after to the world) that specific fermentations are caused by specific ferments; and, moreover, that a disease of wine or beer may be, and often is, simply an undesirable fermentation produced by an invading ferment or germ.

§ 9. — *The Germ or Zymotic (Ferment) Theory of Disease*

It could hardly fail to occur to any thoughtful person that if this were true for certain diseases of wine and beer, it might well be true also for certain diseases of animals;[1] for if we consider step by step the course of any familiar fermentation and then do the same for any familiar infectious disease, we shall discover between them a remarkable similarity. For this purpose we may take the fermentation of apple juice, or cider, and small-pox. The juice of

[1] "Les sciences gagnent toutes à se prêter un mutuel appui. Lorsque, à la suite de mes premières communications sur les fermentations, en 1857–1858, on put admettre que les ferments proprement dits sont des êtres vivants, que des germes d'organismes microscopiques abondent à la surface de tous les objets dans l'atmosphère et dans les eaux, que l'hypothèse d'une génération spontanée est présentment chimérique, que les vins, la bière, le vinaigre, le sang, l'urine, et tous les liquides de l'économie n'éprouvent aucune de leurs altérations communes au contact de l'air pur, la médecine et la chirurgie jetèrent les yeux sur ces clartés nouvelles. Un médecin français, le Dr. Davaine, fit la première application heureuse de ces principes à la médecine, en 1863." — (*Pasteur.*) "La Vie de Pasteur," par René Vallery-Radot, p. 390. Paris, 1900.

apples is hermetically sealed and kept from exposure to air by the apple skin. In the making of cider this skin is broken, the juice is pressed out and of course exposed to the air, to dust, to the press, to the sides of the vessel which receives it, to the strainer through which it passes, etc. At first, and for some time, the juice is sweet, insipid, unfermented, but after some time it is plain that a change is going on. This change is called the "working" or active fermentation of the apple juice, and a closer examination will show that it is accompanied by a slight rise of temperature or "heating" (which is a familiar phenomenon in many fermentations), as well as by obvious chemical changes resulting in the evolution of gas and the disappearance of sugar, in place of which alcohol makes its appearance, giving to the whole process the name of "alcoholic fermentation." The fermentation of any particular portion of apple juice, however, is not indefinitely prolonged. On the contrary, after a comparatively short time the process comes to an end, the evolution of gas ceases, and rest supervenes. Since Pasteur's classical researches we know that what has really happened has been, first, the seeding of the apple juice by (wild) yeast; second, the slow growth of this during the quiescent period; third, its active growth and "working" during the time of obvious fermentation; and fourth, its gradual cessation of activity during the final period. In the case of the infectious disease known as small-pox the history is usually as follows: A susceptible patient must first be *exposed* to the disease, perhaps by contact with a person already affected, perhaps with clothing, letters, food or other materials handled by such a person. After such exposure there is for a time no marked change; but because the disease has been shown by repeated experience to be nevertheless gradually developing, as judged by the result and certain obscure premonitory symptoms afterward recalled, physicians have unanimously agreed to name this the

period of *incubation*. Sooner or later, headache, malaise, and other troubles appear, the patient becomes seriously and obviously ill, a physician is called in, a rise of temperature or *fever* is discovered, the eruption and other marks of small-pox appear, and the patient is plainly affected by active disease accompanied by every indication of profound disturbance and chemical change. But at last, if death does not supervene, recovery ensues, and the patient gradually becomes free from the disease by which he was temporarily overcome. We may add that the barrel of apple juice can undergo the alcoholic fermentation only once, and that the small-pox patient likewise, as a rule, has the small-pox only once. If now we tabulate side by side, and in order, the principal phenomena of an alcoholic fermentation such as that of apple juice, and those of an infectious disease such as small-pox, we shall discover a remarkable similarity between them.

A Fermentation (Apple juice)	An Infectious Disease (Small-pox)
1. Exposure of the juice to air, dust, etc.	1. Exposure of the patient to infection.
2. Repose and then slow change. (Growth of the ferment.)	2. Incubation. (Slow and insidious progress of the disease.)
3. Active fermentation or "working." Evolution of gas bubbles, change of sugar to alcohol. Rise of temperature.	3. Active disease. Eruption, disturbance of the usual functions. Rise of temperature or fever.
4. Gradual cessation of fermentation.	4. Slow convalescence (or death).
5. No further liability to alcoholic fermentation.	5. Immunity to small-pox.

The striking analogy here shown suggests something more. It certainly justifies the suspicion of relationship, and shows well the natural fitness of the term "zymotic" (fermentative) for that class of diseases in which an analogy so remarkable is manifest.

In the next chapter we shall obtain further indications of close relationship between fermentation and disease. Meanwhile, we cannot fail to observe that as soon as it was shown by Pasteur that the phases of an alcoholic fermentation are due to the introduction, growth and chemical work of a living ferment (yeast) finding its way into the apple juice from the air, dust or the outer skin of the apple, it became easy and natural to suspect that small-pox and similar diseases are somehow caused by similar living ferments finding their way into the body of the patient. Thus the "germ" theory of fermentation naturally led to a "germ" theory of infectious disease; and movement in this direction became almost irresistible when Pasteur soon after established a fact of the very first importance, namely, that *the diseases of wine and beer are "germ" diseases*, due to their invasion by, and the growth within them of, undesirable micro-organisms (bacteria or wild yeasts).

General attention was now drawn to the subject, and the germ theory of disease became very widely known when Pasteur, hitherto a mineralogist, chemist and biologist, turned aside from his laboratory studies on the fermentations of wine, beer, vinegar and milk, and, in response to an urgent call from the French government, began a personal investigation of a widespread animal disease, which had hitherto baffled all inquiry. This was the famous "silkworm disease" of which his son-in-law, M. V.-Radot, has given us an admirable popular account. Inasmuch as this brilliant effort of Pasteur was one of the most important factors in drawing universal attention to the germ theory of disease, and inasmuch as it is in itself an inspiring example of a scientific grappling with disease, we may quote at some length Radot's graphic description, as follows: —

§ 10.—*Louis Pasteur and Infectious Diseases of Silk-worms*[1]

"The life of the population of certain departments in the South of France hangs on the existence of silkworms. In each house there is nothing to be seen but hurdles, over which the worms crawl. They are placed even in the kitchens, and often in well-to-do families they occupy the best rooms. In the largest cultivations, regular stages of these hurdles are raised one above the other, in immense sheds, under roofs of disjointed tiles, where thousands and thousands of silkworms crawl upon the litters, which they have the instinct never to leave. Great or small, the silkworm-rearing establishments exist everywhere. When people accost each other, instead of saying 'How are you?' they say 'How are the silkworms?' In the night they get up to feed them or to keep up around them a suitable temperature. And then what anxiety is felt at the least change of weather! Will not the mulberry leaves be wet? Will the worms digest well? Digestion is a matter of great importance to the health of the worms, which do nothing all their lives but eat! Their appetites become especially insatiable during the last days of rearing. All the world is then astir, day and night. Sacks of leaves are incessantly brought in and spread out on the litters. Sometimes the noise of the worms munching these leaves resembles that of rain falling upon thick bushes. With what impatience is the moment waited for when the worms arrive at the last moulting! Their bodies swollen with silk, they mount upon the brambles prepared for them, where they shut themselves up in their golden prisons and become chrysalides. What days of rejoicing are those in which the cocoons are gathered; when, to use the words of Olivier de Serres, the silk harvest is garnered in! . . .

"In the epidemic which ravaged the silkworm nurseries in 1849, the symptoms were numerous and changeable. Sometimes the disease exhibited itself immediately. Many of the eggs were sterile, or the worms died during the first days of their existence. Often the hatching was excellent, and the worms arrived at their first moulting, but that moulting was a failure. A great number of the worms, taking little nourishment at each repast, remained smaller than the others, having a rather shining appearance and a blackish tint. Instead of all the worms going through the phases of this first moulting together, as is usually the case in a batch of silkworms, they began to present a marked inequality, which displayed itself more and more at each successive

[1] "Louis Pasteur: His Life and Labors." By his Son-in-Law. Translated by Lady Claud Hamilton. P. 127 *et seq.* N.Y., Appleton, 1885.

moulting. Instead of the worms swarming on the tables, as if their number was uniformly augmenting, empty spaces were everywhere seen; every morning corpses were collected on the litters.

"Sometimes the disease manifested itself under still more painful circumstances. The batch would progress favorably to the third, and even to the fourth moulting, the uniform size and the health of the worms leaving nothing to be desired; but after the fourth moulting the alarm of the husbandman began. The worms did not turn white, they retained a rusty tint, their appetite diminished, they even turned away from the leaves which were offered to them. Spots appeared on their bodies, black bruises irregularly scattered over the head, the rings, the false feet, and the spur. Here and there dead worms were to be seen. On lifting the litter, numbers of corpses would be found. Every batch attacked was a lost batch. In 1850 and 1851 there were renewed failures. Some cultivators, discouraged, attributed these accidents to bad eggs, and got their supplies from abroad.

"At first everything went as well as could be wished. The year 1853, in which many of these eggs were reared in France, was one of the most productive of this century. As many as twenty-six millions of kilogrammes of cocoons were collected, which produced a revenue of 130,000,000 francs. But the year following, when the eggs produced by the moths of these fine crops of foreign origin were tried, a singular degeneracy was immediately recognized. The eggs were of no more value than the French eggs. It was, in fact, a struggle with an epidemic. How was it to be arrested? Would it be always necessary to have recourse to foreign seed? And what if the epidemic spread into Italy, Spain, and the other silk-cultivating countries?

"The thing dreaded came to pass. The plague spread; Spain and Italy were smitten. It became necessary to seek for eggs in the Islands of the Archipelago, in Greece, or in Turkey. These eggs, at first very good, became infected in their turn in their native country; the epidemic had spread even to that distance. The eggs were then procured from Syria and the provinces of the Caucasus. The plague followed the trade in the eggs. In 1864 all the cultivations, from whatever corner of Europe they came, were either diseased or suspected of being so. In the extreme East, Japan alone still remained healthy.

"Agricultural societies, governments, all the world, were preoccupied with this scourge and its invading march. It was said to be some malady like cholera which attacked the silkworms. Hundreds of pamphlets were published each year. The most foolish remedies were proposed, as quite infallible,—from flowers of sulphur, cinders, and soot spread over the worms, or over the leaves of the mulberry, to gaseous fumigations of chlorine, of tar, and of sulphurous acid. Wine, rum,

absinthe, were prescribed for the worms, and after the absinthe it was advised to try creosote and nitrate of silver. In 1863 the Minister of Agriculture signed an agreement with an Italian who had offered for purchase a process destined to combat the disease of the silkworms, by which he (the Minister) engaged himself, in case the efficacy of the remedy was established, to pay 500,000 francs as an indemnity to the Italian silk cultivator. Experiments were instituted in twelve departments, but without any favorable result. In 1865 the weight of the cocoons had fallen to four million kilogrammes. This entailed a loss of 100,000,000 francs.

"The Senate was assailed by a despairing petition signed by thirty-six hundred mayors, municipal councillors, and capitalists of the silk-cultivating departments. The great scientific authority of M. Dumas, his knowledge of silk husbandry, his sympathy for one of the departments most severely smitten, the Gard, his own native place, all contributed to cause him to be nominated Reporter of the Commission. While drawing up his report the idea occurred to him of trying to persuade Pasteur to undertake researches as to the best means of combating the epidemic.

"Pasteur at first declined this offer. It was at the moment when the results of his investigations on organized ferments opened to him a wide career; it was at the time when, as an application of his latest studies, he had just recognized the true theory of the manufacture of vinegar, and had discovered the cause of the diseases of wines; it was, in short, at the moment when, after having thrown light upon the question of spontaneous generation, the infinitely little appeared infinitely great. He saw living ferments present everywhere, whether as agents of decomposition employed to render back to the atmosphere all that had lived, or as direct authors of contagious diseases. And now it was proposed to him to quit this path, where his footing was sure, which offered him an unlimited horizon in all directions, to enter on an unknown road, perhaps without an outlet. Might he not expose himself to the loss of months, perhaps of years, in barren efforts?

"M. Dumas insisted. 'I attach,' said he to his old pupil, now become his colleague and his friend, 'an extreme value to your fixing your attention upon the question which interests my poor country. Its misery is beyond anything that you can imagine.'

"'But consider,' said Pasteur, 'that I have never handled a silkworm.'

"'So much the better,' replied M. Dumas. 'If you know nothing about the subject, you will have no other ideas than those which come to you from your own observations.'

"Pasteur allowed himself to be persuaded . . . and on June 6, 1865,

started for Alais. The emotion he felt on the actual spot where the plague raged in all its force, in the presence of a problem requiring solution, caused him at once to forget the sacrifices he had made in quitting his laboratory at the École Normale. He determined not to return to Paris until he had exhausted all the subjects requiring study, and had triumphed over the plague.

"One of the most recent and the most comprehensive memoirs upon the terrible epidemic had been presented to the Academy of Sciences by M. de Quatrefages. One paragraph of this paper had forcibly struck Pasteur. M. de Quatrefages related that some Italian naturalists . . . had discovered in the worms and moths of the silkworm minute corpuscles visible only with the microscope. . . . This instrument had already rendered such services to Pasteur in his delicate experiments on ferments that he was fascinated by the thought of resuming it again as an instrument of research. . . .

"In a few hours after his arrival he had already proved the presence of corpuscles in certain worms, and was able to show them to the President and several members of the Agricultural Committee, who had never seen them. . . .

"It was necessary to know if there existed the relation of cause and effect between the corpuscles and the disease. This was the great point to be elucidated. . . .

"One of the first cares of Pasteur was to settle the question as to the contagion of the disease. Many hypotheses had been formed regarding this contagion, but few experiments had been made, and none of them were decisive. Opinions, also, were very much divided. . . .

"But whatever the divergences of opinion might be, every one, at all events, believed in the existence of a poisonous medium rendered epidemic by some occult influence. Pasteur soon succeeded, by accurate experiments, in proving absolutely that the evil was contagious. . . . All the disasters that were known to have happened in the silkworm nurseries, their extent and their varied forms, were faithfully reproduced. Pasteur created at will any required manifestation of the disease. . . .

"For five years Pasteur returned annually for some months to Alais. The little house nestling among the trees, called Pont-Guisket, became at the same time his habitation and his silkworm nursery. . . .

"All the obscurity which enveloped the origin of the diseases of silkworms had now been dispelled. Pasteur had arrived at such accurate knowledge both of the causes of the evil and their different manifestations, that he was able to produce at will either *pébrine* or *flacherie*. He could so regulate the intensity of the disease as to cause it to appear on

a given day, almost at a given hour. . . . To triumph over this disease (*pébrine*), which was so threatening, Pasteur devised a series of observations as simple as they were ingenious. . . . This process of procuring sound eggs is now universally adopted. . . .

"But if Pasteur brought back wealth to ruined countries, if he had returned to Paris happy in the victory he had gained, he had also undergone such fatigues, and had so overstrained himself in the use of the microscope while absorbed in his daily and varied experiments, that in October, 1868, he was struck with paralysis of one side. Seeing, as he thought, death approaching, he dictated to his wife a last note on the studies which he had so much at heart. This note was communicated to the Academy of Sciences eight days after this terrible trial.

"A soul like his, possessing so great a mastery over the body, ended by triumphing over the affliction. Paralyzed on the left side, Pasteur never recovered the use of his limbs. To this day (1884), sixteen years after the attack, he limps like a wounded man."

§ 11. — *Sir Joseph (now Lord) Lister and Infectious Diseases of Wounds. Sanitary (Aseptic) Surgery*

Stirred by the investigations of Pasteur, and reflecting upon their significance, Sir Joseph Lister, already an eminent surgeon of Edinburgh, became convinced that many wound diseases are probably infectious and, if so, preventable. Accordingly, he set to work, and by the use of antiseptic dressings, sprays, instruments, etc., soon established his thesis and paved the way for the modern practice of sanitary or aseptic surgery, which was not only the first-fruit, but is also hitherto the most brilliant of the triumphs, of the germ theory of infectious disease. By its aid surgery has been not only revolutionized but also vastly extended. Operations formerly dreaded are now done with perfect assurance and constant success. The operating rooms of hospitals are built and conducted almost solely with reference to the exclusion or control of those micro-organisms (germs) which are now universally recognized as the principal enemies of the patient and the worst foes of the surgeon.

CHAPTER III

ON THE RISE AND INFLUENCE OF BACTERIOLOGY. TRANSFORMATION OF THE ZYMOTIC INTO THE ZYMOTOXIC THEORY OF INFECTIOUS DISEASE

"Within the world of life to which we ourselves belong there is another living world, requiring the microscope for its discernment, but which, nevertheless, has the most important bearing on the welfare of the higher life-world." — TYNDALL.

"In der Aussenwelt, welche die alltägliche Umgebung des Menschen bildet und den Gegenstand der hygienischen Forschung ausmacht, findet der aufmerksame Beobachter in weitester Verbreitung Organismen, die an der Grenze der Sichtbarkeit stehen, selbst für das mit besten optischen Hülfsmitteln gerüstete Auge, die aber mit ihrer ungeahnt ausgedehnten, tief eingreifenden Thätigkeit eine hochwichtige Rolle im Haushalt der Natur und im Dasein des Menschen spielen. Sie bewirken die Zerstörung lebloser organischer Substanz, . . . sie erregen die verschiedensten Gährungen und sind uns unersetzliche Hülfsmittel zur Bereitung unserer gewohnten Nahrungs- und Genussmittel; sie befallen andererseits unsere Culturgewächse als Parasiten, die ihren Wirthen Degeneration und Tod bringen; sie veranlassen gelegentlich schwerste Erkrankungen bei niederen und höheren Thieren, und selbst den Menschen bedrohen sie mit mörderischen Epidemien."

— FLÜGGE.

§ 1. — *The Achromatic Microscope Objective*

REFERENCE was made in the last chapter to the influence of the newly discovered achromatic microscope objective upon the development of the germ theory of fermentation and its corollary the germ theory of disease. Its aid was also now being felt from a somewhat different direction, namely, from purely zoölogical and botanical studies of the lowest forms of life. Pasteur's studies on wine and beer,

on the "organized corpuscles" of the air, and on the diseases of wine, beer and silkworms, had pointed downward into the world of the "infinitely little" as the source of those "germs" of life which seemed so small and yet so potent in fermentation and disease. All eyes, therefore, were turned in that direction, and extreme interest and curiosity were felt to know all that could be learned of the lowest forms of life, popularly described as "germs." This interest and curiosity were intensified, no doubt, by the rise just at this time of Darwinism, which also pointed downward for the beginnings of organic species to equally mysterious microscopic and primitive "germs" of life. As a result of these various inquiries one group of micro-organisms or germs, the *Bacteria*, then only recently studied by botanists, and lately located in the vegetable kingdom, became and has ever since remained of the first importance to sanitarians and ætiologists.

§ 2.—*Animalcula, Vibrionia, Bacteria*

The compound microscope is believed to have been invented about the middle of the seventeenth century, and micro-organisms, some of which were probably bacteria, were seen by Kircher (1650), figured by Leeuwenhoek (1680) and, because they were capable of motion, received as a group the name *Thierchen* or *animalcula, i.e.* "little animals" or "animalcules." The compound microscope of the seventeenth century, however, was a very poor instrument and that of the eighteenth century little, if any, better. The best evidence of these facts is that many microscopists actually abandoned the use of the compound microscope of the day, preferring the simple microscope of lower power but comparative freedom from aberrations to the compound instrument of the time with its colored and distorted images. We need not be surprised, therefore, to learn that the microscopists of the eighteenth

century made but small progress in the territory of the "animalcules." The first important and extensive advance upon the work of Leeuwenhoek was made a hundred and fifty years later, and with the aid of the newly discovered achromatic objective, by Ehrenberg (1838) and his contemporaries. The vast horde of forms originally called "animalcules" had, it is true, by this time been separated into two or three main divisions, only one of which is of consequence to us, namely, the *Vibrionia*, a group of the *infusorial animalcules;* and in 1850 the suspicion for the first time found expression that these are not all, or necessarily, animal forms, for in that year a young physician of Boston, Dr. Waldo Irving Burnett, read before the American Association for the Advancement of Science a paper entitled "The Family of Vibrionia (Ehrenberg) not Animals but Plants." His proofs were unsatisfactory, but the idea steadily grew until in 1857 Nägeli, the distinguished botanist of Munich, definitely and finally classified the *Vibrionia* as plants, giving to them the name of *Schizomycetes* — "fission plants." To show that the earlier names still prevailed for a time, however, we need only mention the fact that Pasteur in his earlier papers frequently refers to these forms as "infusorial animalcules" or "corpuscles." A long step forward was made when, in 1872, Ferdinand Cohn, of Breslau, began the publication of a series of papers entitled "Investigations on Bacteria."[1] From that time onward the word "bacteria" has largely replaced the term "germs" in England, America and Germany. In France the term "microbes" seems to be preferred, and much can be urged in its favor. A synonym for this is extensively used in Germany, Great Britain and America, namely, "micro-organisms." Both terms are useful as including animal as well as plant forms; and all of these terms may be said to be partial modern equivalents of the older term "animalcules." All of them

[1] "Untersuchungen über Bacterien," *Beiträge zur Biologie.*

include living "ferments" capable of producing profound, though often invisible, changes in organic substances, and of causing singly or in coöperation those mysterious processes called fermentation, putrefaction, decay and sometimes infectious disease. The bacteria alone belong exclusively to the vegetable kingdom.

§ 3. — *The Foundations of Bacteriology laid by Louis Pasteur*

It has already been told in the previous chapter how the labors of Louis Pasteur served to establish the "germ" theory of fermentation and prepared the way for a "germ" theory of disease. His labors bore fruit also by laying for all time the secure foundations of what has since come to be a new branch of science, namely, bacteriology. Pasteur was not the first to use the microscope in studies on fermentation, but he was the first to employ careful *cultivations* of the micro-organisms concerned, and special importance belongs to his constant attempts to secure "pure cultures" of yeast and other living ferments. It is true that he was compelled to rely altogether upon *liquid* cultivation, so that the actual purity of his cultures is open to some question; but there is no doubt whatever that by his ingenious and successful use of these so-called "pure cultures" — which led him to the discovery of specific causative germs in certain specific diseases of wine and beer, as well as in normal fermentations, such as the acetic and lactic, not to mention the specific "corpuscles" of the silkworm diseases, — Pasteur earned the high privilege of being regarded as the "founder" of bacteriology. It may be well to state at this point, by way of anticipation and in order to avoid misunderstanding, that the honor of establishing bacteriology as a science upon the foundation laid by Pasteur, belongs to Robert Koch, who, by proving (in 1876) that bacteria are the cause and not the consequence

of a particular disease (anthrax) and by introducing (in 1881) an indispensable method of cultivation—the method of "solid" as opposed to "liquid" cultures—raised bacteriology from a previously dubious position to one of high honor among the biological sciences.

§ 4.—*Micro-organisms the Cause and not merely the Consequence of Disease*

The germ theory of disease was not without strenuous opponents. In particular, the objection was raised that there was as yet no evidence that the germs observed in any disease might not have been caused by the disease itself, they being the consequence and not the cause of it. This was really a sound and valid objection. It had been successfully raised by Liebig against Cagniard de Latour and Schwann, the discoverers of yeast as a living ferment, as early as 1839, and had been silenced in the case of Pasteur's studies on fermentation only with difficulty and by means of his use of needle inoculations and practically pure liquid cultivations. It was now (1865–1875) urged with reason and with vehemence because many absurd claims were being made regarding the discovery of the "germs" of various diseases, based upon mere observation of microbes in the bodies of persons suffering from those disorders or else detected in their food or drink. In such a case it was entirely possible for any one to urge that the patient had first fallen ill and had then been invaded by the germs, the disease being primary and the germs purely secondary and adventitious. This view was forever disproved, and bacteriology for the first time established on a scientific basis by the splendid researches of Robert Koch upon splenic fever, or anthrax, between 1875 and 1878. Koch was a young physician of Wollstein, in Prussia, when he began his studies on anthrax. This disease is not rare in Germany, Russia and other

parts of Europe, and affects mainly cattle, sheep and horses, but also, at times, human subjects. On examining the bodies of cattle dead of anthrax, Koch found with the microscope (as Davaine in 1859 and others before him had found) minute rods or sticks in the blood and other organs, and especially in the spleen. To some observers this had seemed enough to prove that these were the "germs" of the disease; but Koch did not rest here. Following the methods already employed by Pasteur in his researches on yeast, Koch transferred a needleful of blood or other tissue charged with the mysterious rods to a relatively large portion of the clear normal liquid which constitutes the aqueous humor of the ox's eye.[1] After a few days, or even hours, the rods, being alive and able to grow in this liquid, had multiplied enormously, while the portion of tissue carried over with them being dead had not increased but rather diminished. From this first dish a needleful was now similarly transferred to a second large and fresh portion of aqueous humor, which was thus seeded in its turn. From this second a third was eventually seeded, and so on. A little reflection will show that at each transplanting, though many of the rods were carried over, very little, and always less and less, of the original tissue was transferred. Moreover, the rods transplanted soon included few or none of the original rods derived from the diseased animal, but only the innumerable descendants of these in more and more remote generations. It is easy to see that after a number of transplantings not only none of the original diseased tissue could have remained — those things only being represented that had the power of life, growth and reproduction, but also none of the original "germs." This method of cultivating the living plants — for the rods are

[1] If it be asked how he hit upon the use of this liquid, the answer is that such transparent liquids had often been used in the study of animal tissues (histology), being known, because of their occurrence normally in the animal body, as "normal" fluids.

plants — was clearly a kind of horticulture, and it has become known as the method of liquid "cultures." It should not be forgotten that it was first used successfully (for yeast) by Louis Pasteur. If as a result of its use only one kind of micro-organism (yeast, bacterium) finally remains, such a culture is said to be "pure," or "a pure culture"; precisely as a wheat field free from everything but wheat would be a "pure culture" of wheat. Moreover, just as the ripe grains of wheat in a wheat field are not those which were planted but only their offspring, so the rods in Koch's cultures of the third or tenth generation were not those originally sown by the needle or directly derived from the diseased animals. But if the rods so derived really caused the disease known as anthrax, then their own offspring might reasonably be expected to have similar properties and powers, precisely as wheat grains have the properties of the seed wheat. Accordingly, Koch proceeded to inoculate healthy susceptible animals with his pure cultures of anthrax rods, rightly thinking that if these were the germs of the disease they should be able to reproduce it. The result was perfectly conclusive: the inoculated animals promptly died of typical anthrax, and proof now existed, for the first time in the history of pathology, that a specific germ was and is the cause, and not merely the accompaniment or the consequence, of at least one well-known specific, infectious disease.

An immediate result of this brilliant work of Koch was to give a fresh stimulus to the study of the bacteria, already in full cry since the beginning of the classic researches of Cohn, who, in 1875, added to his earlier results the highly important discovery that some bacteria can, and under certain circumstances do, produce *spores* which appear to be protective, highly tenacious of life, and very resistant to destruction by drying, heat, poisons, etc. Moreover, Koch not only readily discovered spores in the rods of anthrax, but also succeeded, as only a very few observers had done

before him, in finding on other germs—notably certain large spiral forms in ditch water—*cilia* or lashes in active motion and presumably locomotor in function. These he (for the first time, in 1877) even succeeded in photographing.[1]

§ 5.—*A New Method of cultivating Bacteria and the Establishment of Bacteriology as a recognized Biologic Science by Robert Koch in* 1881.

Bacteria were probably first discovered in the latter part of the seventeenth century by Kircher and Leeuwenhoek, as has been stated already, but it was not until 1857 that microscopists were able satisfactorily to classify them as plants, and definitely locate them in the natural system. Pasteur observed many of them, for example a lactic ferment, a vinegar ferment and certain disease ferments of wine, beer, etc., and his work on these ferments, as well as on yeast, and especially his use of the method of "pure" liquid cultures, constitutes the basis of the modern science of bacteriology, no less than that of the germ theory of disease. Pasteur is, therefore, undoubtedly entitled to be known as the founder of bacteriology. And yet, owing to the intrinsic and peculiar difficulties of the subject, but little headway was made in exact knowledge of the bacteria themselves, and bacteriology as a distinct science was not established until, in 1881, a new and vastly improved method of cultivating bacteria was introduced by Robert Koch. This method, while extremely simple, was yet so effective and so fruitful that it forthwith became indispensable to many researches in biology.

The method of cultivation which immediately proved so valuable is familiar to all biologists and is known as "Koch's method of solid cultures." Up to 1881 all cultures of yeast or bacteria hitherto made had been "liquid" cultures, such as were invented and used so effectively by

[1] Cohn's *Beiträge*, Bd. II.

Pasteur in his establishment of the germ theory of fermentation and the germ theory of disease.

Koch himself had used only liquid cultures in his great work on anthrax published in 1876; and Lister, Cohn and a host of others who studied fermentation and diseases between 1869 and 1880 had used exclusively liquid cultures. In all these cases, however, it was very difficult to secure *pure* cultures because of the easy mingling in fluid media (such as bouillon or other fermentable or putrescible liquids) of various kinds of microbes, especially if the latter, as often happened, were endowed with the power of independent motion and could swim about. It was only by working on the basis of chance, and inoculating many flaskfuls by single needlefuls, that pure cultures could be got. This was tedious, uncertain, unsatisfactory, and in the hands of any but experts almost sure to lead to wrong conclusions. Thus it happened that during the twenty years after Pasteur began to use liquid cultures, progress in bacteriology was slow and uncertain. We shall now see why, on the contrary, in the same number of years since Koch began his use of "solid" cultures, bacteriology has advanced by leaps and bounds.

The method of solid culture overcomes the worst defects of the method of liquid culture, namely, first, the promiscuous mingling of different kinds of bacteria, and also, second, the time and labor consequently required to secure "pure" cultures. In this method the bouillon, or other liquid medium in which bacteria will thrive, is simply thickened while hot with gelatine or some similar substance such as Irish moss or agar-agar, so that when cooled the mass becomes a soft, moist jelly, capable of being melted by a gentle heat and solidified at the temperature of an ordinary room. It will be apparent on a moment's reflection that any bacteria or similar micro-organisms present in the liquid must also be present in the solid mass, but with this important difference of condition, viz., that

whereas in the liquid they float or swim about promiscuously, and may become thoroughly intermingled, such is not the case in the solidified mass, in which each is brought to rest and held captive at some small distance at least from every other. Moreover, since the "solid" medium contains as abundant nutrients as the "liquid," the bacteria are firmly fixed in a solid which is at once their prison and their food. Accordingly, they continue to feed and multiply or reproduce, though each remains fixed at or very near the point where it was imprisoned. After a day or two, as a result of continued feeding and reproduction, microscopic heaps of bacteria are formed, which finally become visible to the naked eye as minute dots, and when still larger are known as "colonies." If the parent of the colony was, as is usually the case, a single isolated, individual bacterium, the colony, being composed solely of the descendants of this germ, will be a "pure" culture, readily and immediately supplying the material for other pure cultures of the same species. The ease and the saving of time, the simplicity, certainty, and accuracy of the method are obvious. Its superiority to the method of liquid cultures caused its immediate adoption, and it speedily led to the establishment of bacteriology as a recognized biological science.

Almost immediately the new science began to yield wonderful fruit, for in the next year (1882) the whole world was startled at the announcement by Koch of his discovery of the micro-organism of tuberculosis, a bacillus usually found in the sputum of patients suffering from pulmonary consumption, capable of cultivation on solid media outside the human body, and able to produce the disease when inoculated into healthy susceptible animals, such as guinea-pigs. This announcement caused a profound sensation all over the world; but so general and so conclusive was the confirmatory testimony that, in a surprisingly short time, it was accepted, and is now a matter

of history. The next year (1883) witnessed the discovery, also by Koch, of the micro-organism of Asiatic cholera, in this case not a true *bacillus* or rod, but a curved form; hence at first described as a "comma" bacillus and afterward as a *spirillum* or *vibrio*. One year more (1884) yielded the rich prizes of the bacillus of diphtheria and that of tetanus (lock-jaw), as well as new and careful studies by Gaffky, with the improved methods, upon the bacillus of typhoid fever which had been partially worked out previously by Eberth and Koch. Very much, of course, still remained to be done, not only in the search for the germs or living ferments of important and familiar diseases, but also in verifying the steps already taken; but it is no exaggeration to say that within five years from the time of Koch's introduction of the method of solid cultures the new science of bacteriology had achieved a recognized and honorable position. Moreover, the zymotic theory of infectious disease was now established, and the dreams of the iatro-chemists and of William Farr had come true.

We shall next see how the theory of infectious disease as due to living ferments has been gradually further elaborated into a theory of ferment-poisons, or in other words transformed from a *zymotic* into a *zymotoxic* theory.

§ 6.—*How, precisely, do Living Ferments produce Disease?*

A little reflection will show that there are several ways in which invading micro-organisms might conceivably produce disease in the animal body; for example, (1) *by mere physical obstruction*, clogging the capillaries, veins and arteries, and interfering mechanically with the ordinary operation of the vascular and other mechanisms; or (2) *by chemical interference*, such as (*a*) theft of food or other chemical compounds needed by the body, or (*b*) by the

generation of substances harmful to the body and therefore to be reckoned as essentially poisonous or "toxic." It is not necessary to do more than suggest these various possibilities inasmuch as it is now universally agreed that, while other influences should not be overlooked, the principal method of damage lies in the generation of toxic products (*toxins*), resulting from the operation of living ferments within or upon the organism. This will be more readily understood by returning for a moment to a consideration of the alcoholic fermentation. In the case of apple juice invaded by wild yeasts, it is indeed true that the yeasts multiply enormously and enough to cause a physical change, the turbidity of the liquid; and also that sugar, a valuable food substance, disappears by the agency of the yeast. But the most striking phenomenon, and one which has been universally recognized as such, as is proved by the fact that this fermentation has long borne its specific name, is, that a new and toxic substance, *alcohol*, is generated during the fermentation. In a word, just as yeast may be considered the specific germ of the alcoholic fermentation, alcohol may be regarded as the toxic substance generated by it, *i.e.* alcohol may be regarded as a *toxin* produced by yeast.

We must hasten to remark, however, that the products of fermentation are not always or necessarily poisonous either in character or quantity, as may be seen in the case of the alcoholic fermentation just cited and in the vinegar, lactic and similar fermentations. It is however interesting to observe that the character of the substances produced is in each case specific,—yeast producing alcohol, the anthrax germ producing anthrax poison or toxin, the diphtheria bacillus diphtherotoxin, the typhoid fever bacillus typhotoxin, the lock-jaw bacillus tetanotoxin, and so on. But if this be so, then this class of living ferments may easily do its damage by means of its products, which are harmful to the body just as poisons are, and the mystery

of an infectious disease becomes no greater, and perhaps no other, than a mystery of toxicology, such as exists, for example, in the case of poisoning by opium, belladonna, strychnine, and similar vegetable poisons. It is by reasoning of this sort, based upon numerous observations and experiments, that the modern theory of infectious disease has reached the point to which we have now obviously come, namely; that the true theory of infectious disease is not merely a zymotic or ferment theory, but rather a *zymotoxic* or *ferment-poison* theory.

It is plain that the invading micro-organisms which produce disease are essentially parasites, and that the germ theory of disease is a theory of parasitism. The term "zymotoxic" is here preferred to "parasitic" simply as being more definite and more precise. There can be but little doubt, however, that the growth of knowledge of parasitism materially aided the acceptance of the germ theory. Favus and muscardine have already been cited as early examples, and the discovery of trichinæ in swine, and, in particular, the recognition that epidemics may be caused by these microscopic worms doubtless paved the way for a more speedy general acceptance of a parasitic or germ theory of infectious disease. To this aspect of the subject we shall return in the next chapter.

§ 7.—*Sepsins, Ptomaines and Toxins*

It has long been recognized that spoiled meat, fish and other animal foods are sometimes dangerous to eat, and the popular assumption has been that they contained some deadly poisonous substance. As early as 1814, according to Woodhead, Burrows in England described such a poisonous substance in putrefying fish; while Kerner, in 1820, described a poisonous alkaloid which resulted apparently from the decomposition of albumen, and resembled in its physiological action a substance found by him in poison-

ous sausages. Kerner compared this with atropine, the alkaloid of belladonna, in its toxic effects. In 1856 Panum obtained from decomposing animal matter a characteristic product soluble in water or alcohol to which he gave the name "sepsin." No great attention, however, was paid to these substances until about 1870, when Selmi drew general attention to the subject, and gave to the so-called poisonous alkaloids the name "ptomaines," *i.e.* "cadaveric" substances. Nencki and also Brieger soon obtained several of these from pure cultivations of bacteria, and since that time it has been generally recognized that it is easy to separate from substances which have undergone fermentation or putrefaction chemical compounds more or less characteristic of the fermentation or putrefaction in question. When these are poisonous, they are often described as ptomaines; and the whole group is popularly known by this name, though it is obviously unfit for the purpose. Some writers have undertaken to apply the word "leucomaines" to those similarly derived but harmless.

A more recent terminology describes the poisonous products of fermentation or putrefaction as *toxins*, and applies no name to the non-poisonous products. As we shall soon see, the ideas advanced in this paragraph have received widespread attention, and must be regarded as of the highest importance on account of their necessary connection with the subjects of susceptibility and immunity upon which we must dwell in the next chapter.

§ 8. — *Transformation of the Zymotic Theory of Infectious Diseases into the Zymotoxic Theory of to-day. Recapitulation*

Enough has now been said to make it clear that the modern idea of an infectious disease is somewhat more than that of a fermentation or a case of parasitism. It is not merely that the body of the patient is invaded by

germs; our theory goes much farther than this and shows us the germs growing, dividing and multiplying in the body of the patient, while at the same time each carries on its individual metabolic existence, acting upon its immediate environment, drawing to itself foods, and reacting by setting free the special products of its vital activity. It is not enough to suppose that the micro-organisms in question mechanically obstruct or physically disturb the delicate machinery of the living organism in which they multiply. The symptoms of infectious disease are rather those of toxic actions, actual poisonings of the body, accompanied by chills, fever, delirium and other symptoms of a profound disturbance. Moreover, the phases of infectious disease — the slow onset, the active illness, the recovery and the subsequent immunity — are all readily explained upon the modern theory of *zymotoxic* action. The slow onset is apparently due to the limited infection and the time required for the growth of the germs. The gradual increase of severity keeps pace with their multiplication and activity. The height of the disease corresponds to the height of their development. Its abatement to their decline. The subsequent immunity perhaps to the habituation of the organism to their poison. The subject of immunity, however, is by no means well understood. It will be more fully considered in the next chapter.

§ 9. — *Objections to the Germ Theory*

The principal objection to the germ theory was and is, that already referred to as met and overcome by Koch, viz., that germs may be seemingly the consequence, not the cause, of disease. Another objection is that in certain diseases the most careful search has failed thus far to reveal causative micro-organisms. The answer to this latter is simply that in the absence of all positive evidence of the true cause of disease we are at liberty to choose the

most likely working hypothesis, and no hypothesis has yet been found for any infectious disease more reasonable or more probable than the germ theory.

"A great scientific theory has never been accepted without opposition. The theory of gravitation, the theory of undulation, the theory of evolution, the dynamical theory of heat — all had to push their way through conflict to victory. And so it has been with the germ theory of communicable diseases."[1]

[1] TYNDALL, Essay on "Louis Pasteur, His Life and Labors."

CHAPTER IV

SANITARY ASPECTS OF THE STRUGGLE FOR EXISTENCE. PARASITISM. HEALTH AND DISEASE IN TERMS OF GENERAL BIOLOGY. VITAL RESISTANCE, SUSCEPTIBILITY AND IMMUNITY

"Nothing is easier than to admit in words the truth of the universal struggle for life, or more difficult — at least I have found it so — than constantly to bear this conclusion in mind."

"Let it also be borne in mind how infinitely complex and close-fitting are the mutual relations of all organic beings to each other and to their physical conditions of life."

— DARWIN. "The Origin of Species."

§ 1. — *Sanitary Aspects of the Struggle for Existence*

IN the preceding chapters stress has been laid on the potency of the agents of disease proceeding from the environment. This, however, is only one aspect of the matter. In order that living ferments or their poisons shall be effective, there must be a susceptible subject upon which they can act. Thus it comes to pass that in any zymotic disease the energy and virulence of the attacking agents are virtually pitted against the resistance of the patient, and a struggle ensues which may be, and often is, on one side or on both sides a veritable struggle for existence. In this case the struggle is between organism and organism, between man and microbe. In "The Origin of Species" Darwin, in dealing with the struggle for existence, dwells chiefly upon similar struggles of living things one with another, and it is this aspect of the subject which is still most often emphasized. For the

hygienist, however, the struggle for existence means not only competition and battle and their consequences, not only the struggle of organism with organism, but also the broader struggle of the individuals with their whole environment. In the familiar parable of the sower we have a vivid picture of such a struggle for existence in the case of certain seeds:—

"Behold, a sower went forth to sow; And when he sowed, some seeds fell by the wayside, and the fowls came and devoured them up: Some fell upon stony places where they had not much earth; and forthwith they sprung up, because they had no deepness of earth: And when the sun was up, they were scorched; and because they had no root, they withered away. And some fell among thorns; and the thorns sprung up, and choked them: But others fell into good ground, and brought forth fruit."

In this parable both aspects of the struggle for existence are dwelt upon: first the struggle of organism with organism, namely, of seeds with birds and with thorns; and, second, of organism with lifeless environment, namely, with stony places, scorching sun and good earth. A similar breadth of view is required for the student of sanitary science who seeks to gain a philosophic knowledge of the nature of disease; for disease may be the consequence not merely of organism struggling with organism, but also of organism struggling with lifeless environment. It is perhaps most often the result of both hostile organism and unfavorable lifeless environment acting together upon the human mechanism. Of the struggle of organism with organism parasitism affords a familiar and instructive example.

§ 2.—*Parasitism and Infectious Disease*

Some recognition of what is now known as parasitism must have occurred very early in the history of the human

race. It is exemplified, for example, in the case of the gourd which grew up and sheltered Jonah while he impatiently waited for the destruction of Nineveh, inasmuch as a worm was sent in the night to feed upon and destroy the gourd; and it is said that Pliny was familiar with the parasitism of the mistletoe. The word "parasite," however, arose in a different connection and was only recently applied to plants and the lower animals, having been apparently first used for a person who unbidden eats beside, or at the table of, another, and therefore, of course, lives at his expense. A few cases of parasitism, such as that of the mistletoe, were recognized very early because they were so conspicuous that they could not readily be overlooked. The well-known lines of Swift[1] testify unmistakably to a recognition of the same phenomenon. For the most part, however, parasitism remained comparatively unrecognized until the introduction of the compound microscope revealed its almost universal prevalence.

Parasitism is now known to be one of the commonest features of the struggle for existence, and it is not necessarily, as it is often supposed to be, an abnormal and strange development — at least in its beginnings. If, in the search for food, a plant or animal happens to come in contact with and feed upon another, it may easily result that it shall gain great profit thereby, though if this habit becomes so extended as to lead to the destruction of the host, the parasite itself may also perish. It is not difficult to suppose that parasitism may have arisen from sapro-

[1] "So, naturalists observe, a flea
Has smaller fleas that on him prey;
And these have smaller still to bite 'em.
And so proceed *ad infinitum*."

Of which a more popular, alliterative and generalized version is, —

"Big bugs have little bugs
Upon their backs to bite 'em;
And little bugs have lesser bugs,
And so *ad infinitum*."

phytism, in which plants or animals feeding upon dead or waste organic matters happened to become attached to living plants or animals, and it is easy to see how, under these circumstances, great advantage might accrue to the saprophyte. It is even possible to imagine how the ranks of parasites, thinned by the destruction of their hosts, or otherwise, might continually be recruited from among the saprophytes.

The somewhat extended discussion of the germ theory of fermentation and disease in the previous chapter should not lead the reader to overlook the fact that many of the micro-organisms which are the prime movers of fermentation and infectious disease must from another point of view often be regarded as parasites. The parasitic fungi have long been known in special cases to penetrate the tissues of their host precisely as microbes may "invade" the animal body. It has also been known that in doing this some solvent reagent was secreted by the fungus, and experiments have shown that it is possible to separate from particular fungi substances which will corrode and destroy vegetable tissues. It thus appears that a close analogy is discoverable between the toxins or poisonous products of disease germs and these solvent reagents or tissue-poisons.

It is customary to speak of the infectious diseases as essentially parasitic in their character, the disease germs being the parasites, and the organisms affected their hosts. This point of view is not only common, but exceedingly useful, for it places these diseases in the same category with certain well-known phenomena of parasitism (or saprophytism), and makes them thereby the more readily comprehensible. The sanitarian in particular has reason to value this interpretation of infectious disease inasmuch as prevention of parasitism is, in theory at least, a comparatively simple matter, namely, the destruction of the parasites in question and their control in the environment. When it comes, however, to an examination of the precise nature of

the parasitism involved in infectious disease, we shall find it often necessary to regard the germs as parasites producing chemical change and doing damage by the chemical changes which they effect, or the chemical bodies which they produce, rather than by the theft of food substances which is the more ordinary characteristic of parasitism.

The germ theory is sometimes thus described as the parasitic theory of disease, and has also been called the "particulate" theory because the micro-organisms concerned are obviously material particles. This latter designation is of value chiefly as emphasizing the reality of the *materies morbi*, or the fact that the causes of infectious disease are material particles and not merely immaterial conditions such as dynamical derangements of spiritual vital principles. The reader will be the better prepared to recognize the validity of the former term — the parasitic theory — if he will remember that just before the germ theory had taken definite shape two diseases, namely, muscardine in silkworms and *favus* or honeycomb of the human scalp, had already been proved to be due to parasitic fungi (see Chapter II, p. 32). Powerful support for a parasitic theory of disease had also been accumulating during the time of the growth of the germ theory of fermentation and disease, especially in connection with a terrible disease of man hitherto unsuspected, but by that time definitely known, namely, the disease caused by the parasite called the pork-worm (*Trichina spiralis*) and known as trichinosis. This disease is of special interest to sanitarians, inasmuch as the parasites which unquestionably produce it, while very minute are still scarcely to be called micro-organisms, and yet are so small that for a long time they escaped the detection which tapeworms, stomach-worms, etc., readily encountered. They thus form an interesting connecting link between the invisible micro-organisms and the coarsely visible tapeworms, etc., and the smaller fungi. (*Cf.* pp. 293, 296.)

The whole matter may perhaps be summed up as follows: from the widest point of view infectious diseases in common with all others are important and complicated phenomena in the universal struggle of organisms for existence. From a somewhat narrower point of view they are often to be regarded as cases of parasitism; the disease germ being the parasite and the organism affected being its host. From a still narrower point of view, and examining the details of the struggle, the process appears to be essentially "toxic," the host being damaged by the parasite (or saprophyte) not so much by theft of material as by the products of its metabolic activity, namely, by chemical poisons known as "toxins."

§ 3.—*The Lifeless Environment and Disease*

Any extended treatment of this subject would be beyond the province of a work like this, since such a discussion belongs rather to hygiene than to sanitary science. Nevertheless, the student of sanitary science cannot neglect the influence of the lifeless environment as a powerful factor in the causation and modification of infectious disease, even when it is not the principal factor. In such disease, for example, the time, the occurrence, the duration and even the energy of the attack, may be profoundly influenced by external environmental conditions such as season, temperature, dryness or light. We may, therefore, with advantage, consider somewhat carefully the relations between organisms and their environments, whether living or lifeless, before passing on to the more recondite subjects of susceptibility, vital resistance and immunity.

In addition to a comprehension of the fact that the living organism is essentially a delicate physical mechanism, the student requires an adequate knowledge of what is meant by the terms "organism" and "environment," and with this a recognition of the significance of the actions, reactions

and interactions which necessarily go on between organisms and their environments.

In the language of biology an organism is a limited mass of living matter occupying a definite position in space and time. It is bounded on all sides by material substances, — earth, air, water, etc., — by which it is acted upon, and upon which it acts in return, and, on the whole, these actions and reactions are equal, though in opposite directions. Those portions of the material universe which thus act upon the organism are called its "environment," and a little reflection will show that while it is the nearer portions which are most closely concerned and are, therefore, the most conspicuous parts of "the environment," no part, in theory at least, is so remote as to have no influence. The whole material universe may be — must be — divided for any living thing into two parts, namely, that thing and its environment: the individual on the one hand, and the rest of the universe on the other, — very much as the ancient and mediæval philosophers regarded man on the one hand as "microcosm" and the rest of the universe as "macrocosm." Biology teaches that if we would comprehend the doings of living things we must begin by taking this point of view. Viewed from this standpoint mankind becomes a host of masses of matter each bounded by the rest of the material universe, with which it must deal so long as it continues to live, and to which, no matter how prolonged the struggle, it must finally surrender. From the environment each must derive whatever of matter and energy it gains, and to it it must return whatever it loses. It may be profoundly affected by heat or cold, by lightning or earthquake, by fire or tempest; and it may, on its part, react upon its environment and displace the air by buildings or balloons, the sea by ships, the earth by mines or tunnels, or fire by incombustible substances. Every tree that lifts its branches into the aerial ocean reacts upon the atmosphere and, like every animal that burrows into the earth or builds its

house or its nest in the air, reacts upon its environment. The encroachments of the sea may be resisted or overcome by dikes, of the wind by shelters, of the sunshine by shade. Everywhere in nature — and in man as a part of nature — we find actions and reactions incessantly going on, and these in the long run consist essentially of exchanges of matter and of energy or of both, between masses of matter and their environments.

§ 4. — *Health and Disease in Terms of General Biology*

Life has been defined as "the continuous adjustment of internal to external relations," and health might be defined on these terms as the normal state and performance of this adjustment. Disease would then be some serious disturbance or grave departure from this normal state or performance, and might conceivably be due to (1) a failure of the intrinsic powers of adjustment; or (2) some external condition so severe or unusual that the usual adjustment was impossible; or (3) to a combination of these factors. From what was said in the first chapter (p. 12) it is clear that a failure of the mechanism itself to do its part, a failure of the intrinsic powers, such, for example, as old age effects, produces a constitutional disturbance or disease; while external conditions, so hard or so unusual as to be met with difficulty or perhaps not at all, may well give rise to a disturbance or disease essentially environmental in its origin; and the combined effect of imperfect mechanism or imperfect internal adjustment with external relations difficult to deal with might lead to diseases seemingly environmental, but really no less truly constitutional in origin. A very little reflection will show that to avoid disease and to forestall its effects there are required: (1) Mechanisms as capable as possible of adjustment to external relations, unfavorable as well as favorable. (2) Environments (external rela-

tions) to which the mechanism may readily adjust itself, or making as small demands as possible upon its powers of adjustment.

Of these two factors the former is on the whole far the less under our control at present. The mechanism may indeed, as a rule, be strengthened by good air, good food, rest and other favorable conditions; it may be weakened by bad air, bad food, fatigue and other unfavorable conditions; so that it shall adjust more, or less, successfully its internal to any external relations. But while so much is unquestionably true, and while efforts looking in this direction lie at the basis of all sound hygiene and constitute one of its proper functions, it is still true that the external relations to which the internal relations of the mechanisms must be adjusted, are much more largely under our control. In other words, it is to a great extent within our power (in theory at least) to provide environments or external relations to which almost any living mechanism should be able to adjust its internal relations; or, conversely, an environment so unfavorable that few if any could possibly be able to adjust themselves to it.[1]

§ 5.—*Three Principal Sanitary Conditions or States of Relation*

In actual life all these various conditions are readily observed. We find some persons so robust—that is to say, with mechanisms so capable of adjustment to external

[1] "The man who lives to the age of a hundred years and who, during that time, suffers no pain, and is continually able to make use of the powers peculiar to his age, would by universal testimony be regarded as an example of health; yet even the life of such an one would not always be at its best; and health, like every other such name, is to be used in a relative sense. Into the life of the healthiest man disorders must frequently enter. Absolute health is an ideal conception, as the line of the mathematician, the ether of the physicist, and the atom of the chemist."—T. C. Allbutt, "System of Medicine," I, xxii.

relations of whatever kind — that nothing seems to daunt them. They work hard, eat poor food, live in bad air and seemingly disobey all the rules of hygienic living, and yet possess apparently perfect health. Conversely, others surrounded by every sanitary contrivance, well fed, well housed and tenderly cared for, sicken and die in an environment apparently the most absolutely favorable. And finally, in the same community, are many who thrive as long as their external relations are good and easily dealt with ("favorable"), but who suffer just as soon as these become difficult to deal with ("unfavorable").

Furthermore, these groups are by no means fixed and invariable, but rather constantly subject to change both as to membership and mass. A period of unusual environmental severity of climate, temperature, infection, financial or political buoyancy or depression, may promote or reduce from one rank to another, with the consequence not only of numerous changes in actual sanitary conditions in individuals, but even extensive improvement or deterioration in the average public health of a community. Of this a good example is some effective change in external relations, such as a financial panic, causing anxiety, loss of employment, increased exposure, poorer feeding, loss of sleep, etc., but perhaps the best example is one in which a novel and direct action proceeds from the environment, unknown, it may be, until its work is done. Such a profound change in the external relations of an entire community occurs when some epidemic, unsuspected, falls upon an entire city or town. There are on record many cases of this kind, some of which are described in the eighth chapter. If, for example, a public water supply becomes contaminated with the germs of an infectious disease such as typhoid fever, the general standard of health in the community using it will be lowered, the weak, as a group, will, on the whole become weaker, the strong, less strong, and some of each group will perish altogether

who would have lived longer if the infection had not reached them.

The explanation of these three great groups — which we may call "the robust" or "the strong," "the well but not strong," and "the feeble" or "weak" — is simply that there are actually corresponding groups of organisms, or mechanisms, in every community. The "strong" are those endowed by nature, by inheritance, or it may be to some extent by training, with superior vital machinery. "The well but not strong" are similarly provided with machinery either poorer in quality or less successfully put together, while the "weak" or "feeble" are those having vital mechanisms so delicate in fibre or adjustment as to be always in need of attention or repair, even under ordinarily good conditions. It will be observed that no place is here left for those organisms which are altogether wanting in the power of "continuous adjustment of internal to external relations." Such are those that perish, — some, before they are born; some, vainly trying at birth to catch the first breath of life in order themselves to effect an oxygenation of their blood, hitherto provided for from the mother, from the novel atmospheric ocean in which if anywhere they must henceforward live; some, later, in that struggle for existence which compels them to deal with bad food, or exposure, or infection, or with sorrow or shame. Few, comparatively, are able to adjust their internal to their external relations so successfully as to reach the familiar threescore years and ten; fewer still the fourscore years; and we have the authority of the psalmist that in the latter case it is only "by reason of strength" that the goal is reached: favorable environments — favorable external relations — alone are not sufficient. The power of adjustment of internal relations is equally indispensable.

§ 6.—*Practical Importance of these Considerations*

The practical importance of these considerations is immense. Any one who deals chiefly with those more violent changes in the environment which produce great destruction in a relatively short space of time is tempted to minimize the importance of forces acting more slowly over longer periods. The epidemiologist, for example, after witnessing the conspicuous effects of an outbreak of disease affecting a whole community through impure food or drink, is strongly tempted to overlook the relatively remote effects of ordinary filth or foul air. And these are in fact far less striking, even when discoverable at all. But yet there is reason to believe that even quantitatively considered they may do quite as much or even far more harm in the long run, for the great epidemics come seldom, affect a small number only, and pass quickly; while filth and bad air act unfavorably upon a much larger number for a much longer time, keeping them frequently and perhaps constantly weakened, and enhancing always their susceptibility to specific disorders.

Nor must we allow ourselves to be deceived by appearances. It is true that abounding health is often exhibited by those dwelling in most unwholesome places, and that many who never wash outlive many who do. But this does not mean that sanitary dwellings are superfluous, or that bathing is a waste of time. Nothing is plainer in sanitary science, as in human experience, than that "Cleanliness is next to Godliness," and that on the whole the first external condition of health is cleanliness. On looking closely we shall find that the cases observed are exceptional, or that the persons in question are the strong survivors of many now dead among whom they represent the survival of the fittest; or that they have really bathed in their own sweat, thus shedding off the outer skin and with it much dirt and many micro-organisms; or finally, that although the sur-

viving younger members of the family may seem hale and hearty, the elders, while still young in years, show the effects of the struggle for existence and often break down or succumb to disease before their natural time.

Darwin somewhere refers, more in sorrow than in anger, to those persons who have failed to understand him because they were utterly unable to appreciate the cumulative effects of small changes acting over long periods of time. The sanitarian needs constantly to be warned against the neglect of small and seemingly insignificant factors of disease in the form of unfavorable conditions which by their prolonged action and cumulative effects may produce great results.

§ 7. — *Vital Resistance and Susceptibility*

The reader is now in a position to understand in its general aspects the term "vital resistance." In the last analysis this expression is used to describe that condition of the normal body, plant or animal, in which it is able to cope more or less successfully with unfavorable influences acting upon it from without, *i.e.* from the environment. There is, however, no quantitative measure of vital resistance; but when it is regarded as small or altogether wanting, the term is no longer used, and the organism is said to be not vitally resistant, but "susceptible" or "vulnerable" to disease. At the other extreme, when the vital resistance is complete, especially in regard to parasites, poisons, etc., the organism is said to be "immune," as are, for example, the arsenic eaters of Styria against ordinarily lethal doses of arsenic, and as are certain trees to certain parasites. Enough has perhaps already been said in the previous section in regard to susceptibility of different degrees, but immunity is a matter of so much practical importance that it will be necessary to consider it much more carefully in the following sections.

It has been suggested by Professor Theobald Smith that the mutual relations of vital resistance and infectious disease may be the more clearly appreciated by expressing them in the form of an equation, namely, $D = \frac{M}{R}$, in which D represents the disease, M the micro-organism and R the vital resistance of the organism attacked. Obviously, D will vary according to the relative values of M and R. It is even possible to carry this idea somewhat farther and to write the equation $D = \frac{MNV}{R}$, N representing the number of micro-organisms and V their virulence; for there is good reason to suppose that the intensity of the disease depends on these factors as well as, though less than, on M, the specific character of the micro-organism involved. We are unable at present to resolve R into any component elements or even to picture to ourselves, except in the most general way, its origin or mechanics. We may, it is true, safely consider that it is bound up with chemical and physical processes which result in favorable chemical and physical conditions; but concerning these processes, and to a great extent these conditions, we are at present almost completely ignorant. (*Cf.* pp. 98, 218.)

§ 8. — *Immunity*

Examples of comparative immunity to infectious disease are familiar in the cases of all robust and healthy persons. Precisely what the basis of this immunity may be it would be difficult to say, but it is not inconceivable that in an organism which is a practically perfect mechanism the conditions should be such as to ward off effectually all micro-organisms, either by mechanical or physiological defences. Among the former would be healthy and vigorous skins and epithelia, which the invaders should find it impossible to penetrate; among the latter, juices of the body of such composition as to be essentially toxic or destructive for

invading microbes. There is good reason to believe that such conditions are, in fact, some at least of those which constitute the robustly healthy organism immune to all ordinary infectious diseases.

It has long been the ambition of dreamers to find some substance which should not only ward off the attacks of infectious disease but also interfere with the ordinary course of Nature, and postpone for a longer or shorter time the arrival of old age. Various elixirs of life have been put forward by enthusiasts, especially with a view to the latter result, and it must be allowed that, improbable as it is that this end will ever be achieved, it is not perhaps theoretically inconceivable. It is plain, however, that inasmuch as there frequently exists already a remarkable natural immunity to certain infectious diseases, the problem of artificial immunity to disease is one much easier; and when we learn, as is the fact, that such immunity has actually been produced in the case of some diseases, we may confidently expect that it shall be eventually brought about in the case of other diseases also.

§ 9.—*Immunity to Small-pox. Inoculation*

The development of our knowledge in this direction is interesting and instructive. The first systematic steps toward securing artificial immunity from disease appear to have been taken in the case of small-pox. In the early part of the eighteenth century, Lady Mary Wortley Montagu, the wife of the British ambassador at Constantinople, the daughter of a duke and the granddaughter of an earl, and a woman of rare gifts, in interesting letters sent from Constantinople to friends at home pointed out that the Turks, in pursuance of a custom apparently derived from the East, were in the habit of "inoculating" against small-pox. Lady Montagu wrote from Adrianople in 1717: "Every year thousands undergo this operation, and the

French ambassador says pleasantly that they take the small-pox here by way of diversion, as they take the waters in other countries. There is no example of any one having died of it, and you may believe I am satisfied of the safety of their experiment since I intend to try it on my dear little son." Largely as a result of this correspondence the practice of inoculation was introduced into England, and thence carried to America. In both countries it became widely extended, and lasted for many years. It is said that the first person inoculated in England was Lady Montagu's daughter. George I and several members of his family were soon after inoculated, as were also many less noted persons, and the practice gradually became common.

In the process of inoculation for small-pox, some "matter" derived from a pustule of a small-pox patient was introduced under the skin of a healthy person who elected to suffer from the disease while well, and knowingly, rather than to run the risk of "taking" it when less well, unknowingly. The process was much the same as that employed in vaccination except that the "matter" used was derived directly from the pustules of a small-pox patient, and was not "vaccine" matter, *i.e.* was not derived either directly or indirectly from the cow. Inoculation had a very extended vogue and was justly regarded as a most important defence against small-pox; and until the milder method of inoculating "vaccine" matter, *i.e.* matter derived from the cow, was devised by Jenner, no other method of prevention of small-pox, or, for that matter, of any infectious disease, was known or practised.

The attitude of mankind at various times toward small-pox, inoculation and vaccination forms one of the most remarkable chapters in the history of the human race. It is impossible to-day to realize the dread and awful terror with which this horrible and most loathsome disease was justly regarded by our ancestors before the introduction of

inoculation and vaccination. A single brief quotation may help to give the reader some idea of the feeling in regard to it and its prevalence, even as late as the middle of the eighteenth century. "Small-pox has been for ages, and continues to be, the terror and destroyer of a great part of mankind. . . . In the ordinary course and duration of human life scarce one in a thousand escapes the small-pox." . . . (Appendix to Dr. Brooke's "General Practice of Physic," London, 1766.) It would be easy to multiply authoritative statements of the fearful ravages of this disease, and to bring forward testimony to its abundance, contagiousness and foul character. Fortunately, it has become to-day in civilized countries so uncommon that the former dread of it has largely disappeared from the popular mind. Unfortunately, however, unfamiliarity with it has bred a contempt for it which leads many to despise, undervalue or refuse the means by which it is chiefly kept in abeyance. Such contempt is likely, if it becomes general, to carry with it its own punishment, for small-pox is so contagious that its recrudescence at any time in any community is natural and easy, if the very simple means in our possession for holding it in check are long neglected.

The art of inoculation for the prevention of small-pox appears to have been long known and to have come to Constantinople from the East — from the Circassians in one direction and from the Chinese in another. By the Chinese the dried pustules are said to have been kept in bottles, inoculation being produced, when desired, by placing portions of these pustules in the nose of the patient.

The results of inoculation appear to have been remarkably successful and under favorable circumstances to have approached, though they did not equal, those attained by vaccination. Sir George Baker, a distinguished authority, writing in 1766, affirms, "According to the best information which I can procure, about seventeen thousand have been thus inoculated, of which number no more than five or six have died." Another writer of the same time says, "Scarce one in one hundred miscarries, whereas a fifth or a sixth part die of the natural small-pox." Dr. Hadow, of Warwick, is said to have practised inoculation for twenty-seven years, and out of 2143 persons inoculated only three

(children) died: of these one of an overdose of opium, one in very hot weather, the third of nose bleed.

Much importance was attached by the best practitioners to "preparatory treatment" of various kinds, although in the East this was less regarded. Sir George Baker quotes Gatti, "who some time ago was much employed in inoculation at Paris" as "an enemy to any general plan of preparation. In all the Levant, he says, where the natural small-pox is as fatal as elsewhere, and where you may find old women who have inoculated ten thousand people without an accident, the only inquiry is, whether or no a person is prepared by Nature. All that is considered is whether the breath be sweet, the skin soft, and whether a little wound in it heals easily. Whenever these conditions are found, they inoculate without the least apprehension of danger." ("An Inquiry into the Merits of a Method of Inoculating the Small-pox," etc., London, 1766.) In America, where inoculation was also much practised before the introduction of vaccination, preparatory treatment was common, and Sir George Baker (*l. c.*) states on the authority of Dr. Huxham that "Dr. Benjamin Gale, of Connecticut, in New England, since he has given mercury and antimony in preparing persons for inoculation, has lost only one person out of eight hundred inoculated." (On inoculation in New England, see Dr. Zabdiel Boylston "An Historical Account," etc., Boston, 1730; in Massachusetts, see J. M. Toner, in *Mass. Med. Soc. Trans.*, Vol. II, p. 151, Boston, 1867; in Great Britain, see W. Woodville, "Hist. Inoc. Small-pox," etc., London, 1796.) For Dr. Gale's paper see *Phil. Trans. Roy. Soc.*, London, 1765.

The drawback to inoculation was that persons inoculated had for the time being mild cases of genuine small-pox, and were therefore capable of conveying the disease to others. They became, temporarily at least, "foci of infection," and were usually treated as such, being often gathered together in inoculation "hospitals" or establishments in relatively remote and inaccessible places, and kept meanwhile under more or less strict quarantine regulations. Those who voluntarily resorted thither for inoculation naturally went, or were sent, while in good health or well "prepared," and, for the time being, were completely separated from their families. It was a successful, but rather dangerous and troublesome method of combating the disease, and when vaccination, equally and perhaps more protective and neither difficult nor dangerous, was introduced (in 1796), inoculation fell into disrepute and was finally forbidden by law (in 1840, in England). Like its successor and superior, inoculation of *cow-pox* (vaccination), the practice of inoculation of small-pox met with strenuous contemporary opposition, but the esteem in which it was held by the most eminent physicians and scientific men of the time is sufficient evidence of its value. "It

cannot be, likewise it ought not to be, concealed that some of the inoculated have died under this process even under the care of very able and experienced practitioners. But this number is so small that when compared with the mortality attending the natural smallpox it is reduced almost to a cypher." (Dimsdale, "The Present Method of Inoculating for the Smallpox," etc., London, 1767).

Inoculation for small-pox will always remain for the student of hygiene one of the most interesting episodes in the development of sanitary science,[1] for it illustrates in the clearest manner some of the fundamental phenomena of infection, susceptibility, vital resistance and immunity — and these are among the principal problems of hygiology.

§ 10. — *Vaccination*

Vaccination (*Vacca*, cow) is simply a modification of inoculation in which "matter" of cow-pox taken originally from the cow is substituted for "matter" of small-pox taken from man. It is immaterial for our present purpose whether cow-pox is or is not small-pox in the cow. The important fact is that inoculation of the matter of cow-pox into the body of human subjects is believed by those most competent to pronounce an opinion to prevent or weaken the virulence of small-pox in such subjects. Experts are unanimous in this opinion, and the methods and results of vaccination — the immortal discovery of Jenner in 1796 — are too familiar to require comment. By its universal application small-pox, as experience shows, can be not only held in check but virtually exterminated.

In its infancy vaccination, like inoculation, had to encounter strong opposition based upon ignorance and a natural dread. "Discoveries in physic, as in every other

[1] Jonathan Edwards, the famous New England theologian, was installed as President of Princeton College on February 16, 1758, when small-pox was prevailing in the neighborhood. As an act of precaution he was inoculated, although after some hesitation and while he was in poor physical condition, and died thirty-four days after his inauguration.

science, are in their infancy liable to censure and opposition; and as the present system of inoculation is of so extraordinary a kind, it would not be strange if a greater portion of both than usual should fall to its share." (Dimsdale, *l. c.*, 1767.) The remarkable fact is that long after its success has been abundantly demonstrated, and after its period of "infancy" may be regarded as having been long since passed, the practice of vaccination should still be not only rejected but also violently attacked by some persons of intelligence. The fundamental reason for this paradoxical state of things is, doubtless, that assigned above by Baron Dimsdale, namely, the "extraordinary" character of a treatment which consists in "inoculation" of any kind. Persons who of their own motion or on the advice of their physicians will cheerfully and even eagerly swallow "medicines," often of a poisonous character, the very names of which are unknown to them, will sometimes refuse to obey their medical advisers when these recommend vaccination, —the former custom being "ordinary" and hoary with age, the latter still comparatively novel and "extraordinary."

The precise mechanism of that immunity which is the most remarkable and most valuable sequel of inoculation (or vaccination) is still a mystery. Some light, however, has been shed upon the problem by the discoveries of Pasteur, Metschnikoff and Behring, and their successors, to a consideration of which we may now turn.[1] (*Cf.* p. 318.)

§ 11.—*Pasteur and Attenuation*

While germs or microbes characteristic of small-pox or of cow-pox have never yet been satisfactorily isolated, analogy compels us for the present to assume their existence. A consideration of the corollaries resulting from the application of the germ theory to these long-known and

[1] For an excellent short modern treatise, see "Vaccination," by S. M. Copeman (Macmillan), 1899.

world-famous diseases led Pasteur, in 1877, not indeed to a solution of the problem of immunity, but to an important extension of the art of vaccination, and new and interesting examples of the immunity-phenomenon. Pasteur reasoned that, if an infectious disease be really a struggle for supremacy between man and microbe, it is probable that in vaccination for small-pox the struggle is less severe for the patient because the germs of small-pox have somehow been weakened or enfeebled by their residence in the cow. If this hypothesis were correct, he might hope to lessen the virulence of any microbe by subjecting it to an unfavorable environment or treatment. Heat, cold, dilution, starvation, overfeeding, etc., suggest themselves as possible agents for weakening virulence; and by experiment Pasteur actually produced enfeebled or "attenuated" cultures of anthrax, chicken cholera, etc., with which he was able successfully to "vaccinate" (if the term may still be used) various animals, rendering them more or less immune to the diseases respectively investigated. In a dramatic public demonstration, in 1880, Pasteur proved conclusively the practicability of his method, which, since that time, has passed into common use in France for the vaccination of domestic animals.[1] (*Cf.* pp. 321–324.)

As a result of Pasteur's labors, fresh examples of immunity were provided, and the practicability of its artificial production was strongly emphasized; but the basis of immunity or the physiological mechanics by which it comes to pass and persists remained as great a mystery as ever.

§ 12. — *Metschnikoff and Phagocytosis*

A highly ingenious theory of immunity was suggested in 1882 by E. Metschnikoff, who, starting with the well-known fact that the white blood-cells are eating-cells (or

[1] See "Louis Pasteur: His Life and Labors" (Radot), New York, Appleton, 1885, pp. 229–246.

phagocytes) and readily devour yeast-cells, bacteria-cells, etc., made elaborate and important investigations tending to show that, in the struggle between man and microbe which may be said to constitute the essence of an infectious disease, the battle is really between the white blood-cells and the microbes, after the latter have somehow secured entrance into the body proper, and especially into the blood-vessels. Metschnikoff's theory of immunity is therefore known as the theory of phagocytosis. It has the merits of simplicity and picturesqueness; but, while doubtless containing much that is true, it fails at one of the most important points, namely, in explaining the persistence of immunity long after the disease is over except indeed on the somewhat too anthropomorphic theory that the phagocytes have become "trained" or "educated." It fails, also, to account satisfactorily for some of the remarkable phenomena afforded by blood-serum experiments, such as those now to be described.

§ 13.—*Behring and Antitoxic Serums*

In 1892 an entirely new line of experiment was opened up by Behring and Kitasato in their work on diphtheria. It was discovered by them that the serum of an animal which had been made immune to the toxin of diphtheria was able, even in a test-tube, to neutralize or impair the virulence of such a toxin, and further that the serum of a non-immune animal was not able to do this. Clearly, then, substances exist in the serum of an immune animal which were not there before the process of immunization, and our present theory of immunity rests upon this fact. The process of immunization according to the serum theory may be described as follows: the microbe (or its toxin) irritates the cells of its host; these produce defensive substances or antidotes (antitoxins), which tend to neutralize the poison, or to inhibit the activity, of the microbe, or both.

If we assume victory for the cells, we have temporary immunity or convalescence. Victory for the microbe means continued disease or death. If we may assume that the cells of the body continue to secrete more or less of the defensive substances, or that they remain for a long time peculiarly sensitive to even minute doses of the toxin in question, we can understand the persistence of more or less immunity. But these assumptions, while plausible and perhaps reasonable, are purely hypothetical.

If we assume, as we may if we like, that the phagocytes of Metschnikoff are the principal productive sources of antitoxic substances, we have a certain harmony between the two rival theories which is, to say the least, conceivable. Much, however, remains to be done before any theory of immunity can be received as more than very imperfectly explaining all of the facts.[1]

§ 14.—*Serum as Cure and Serum as Prevention*

The practical outcome of Behring's work has been of immense importance, especially in the cure and prevention of diphtheria. Patients suffering from this disease, and persons exposed or likely to be exposed to it, may and do have their own antitoxic serum reënforced by the antitoxic serum of the horse or other immune animal and thus are materially aided in their battle with the microbes. The process is simple. Microbes of diphtheria are cultivated in a richly nutrient liquid which gradually becomes charged with their toxin. The liquid is filtered, and portions of the toxin-bearing filtrate are subcutaneously injected into horses, beginning with small doses and continuing until the animal is immune to large doses. Blood is then drawn from the immune horse, and the serum from this blood is

[1] For further remarks on Vital Resistance and Immunity, see Chapter V, § 6, and Chapter XIII.

found to contain antitoxin in abundance. This serum is carefully filtered and then used subcutaneously as a reënforcing remedy for persons actually ill with diphtheria, or as a preventive medicine by those who either may be or may have been "exposed" to it. The results of the serum treatment have everywhere been most significant and encouraging.

§ 15.—*Recapitulation*

This brief statement of our present attitude in respect to infectious disease must suffice for the student of sanitary science. Those who desire to go further along these lines should consult the numerous excellent manuals of bacteriology, in which they will find a rich store of materials to draw upon. It is enough for the student of sanitary science to know that infectious diseases are now believed never to arise spontaneously or *de novo*, but only more or less directly from antecedent cases of the same disease. It is believed that in every instance there must be an actual invasion of, or at least contact with, the susceptible patient by the micro-organism of the disease in question. Once inside or upon the patient, the micro-organisms may grow and multiply, producing at the same time their own peculiar toxin or toxins, precisely as yeast, whether in wine or beer or other fruit juices, produces alcohol as one outcome of its peculiar vital activity. The illness of the patient is believed to be due to the effect upon his body of these specific poisons, by which he may die, or to which he may become habituated. In the latter case he is said to be *immune*, very much as the smoker becomes immune to considerable doses of tobacco, or the arsenic eaters of Styria to heavy doses of arsenic, or opium eaters to opium. The physiological mechanism of immunity is still to a great extent a mystery, but one feature of it appears to be a cellular reaction to the foreign toxin, accompanied by the production of antidotal substances (antitoxins) capable of

neutralizing the microbic poisons (toxins). Whether the cells once affected may be said to have become "habituated" to the poison, and if so what, precisely, such "habituation" means, is less clear, and further investigations are required to elucidate this part of the problem. Meantime the practical value of the work already done is very great, and the antitoxic serum for diphtheria has become one of the most important weapons of the physician and the sanitarian.[1]

[1] The author is indebted to Dr. J. H. McCollom, Instructor in Contagious Diseases in Harvard University, and Resident Physician, South Department (Contagious Diseases), Boston City Hospital, for the following facts: —

Before the advent of antitoxin the fatality in cases of diphtheria (in hospitals) varied from 30 to 50 per cent. In 11,598 cases in the Asylums' Board Hospitals, London, without antitoxin, it was 30.3 per cent. In the same hospitals, with antitoxin, it has been 18.4 per cent. In the Boston City Hospital, without antitoxin, the recent fatality was 46 per cent; with antitoxin, it has been 12.9 per cent. Bayeux, in his work on diphtheria, gives 55 per cent without, and 16 per cent with, antitoxin, the latter figure being based on an analysis of more than 200,000 cases. Bayeux adds that not a single death has been clearly demonstrated to have been due to the use of the serum.

Other statistics may be found in *Quar. Pub. American Statistical Assoc.*, VII, 53 (June, 1901), and in *32d Ann. Rep. State Board of Health of Massachusetts*, for 1900, p. 768.

PART II

INFECTION AND CONTAGION: THEIR DISSEMINATION AND CONTROL

CHAPTER V

ON INFECTION AND CONTAGION: THE PATHS AND PORTALS BY WHICH THEY ENTER THE BODY; THE RESISTANCE WHICH THE BODY OFFERS; THE VEHICLES BY WHICH THEY ARE CONVEYED; AND THE PLACES OF THEIR ORIGIN. ANIMALS AND THEIR EXCRETA AS SOURCES AND PRIME MOVERS OF INFECTION

"Für die Verbreitungsweise der Infectionskrankheiten kommen zunächst in Betracht die Infectionsquellen, die Transportwege, welche von dort zum Menschen führen, und die Invasionsstätten, an welchen das Eindringen der Infectionserreger in den gesunden Körper erfolgt. Sodann haben wir der individuellen Disposition und der Immunität besondere Beachtung zu schenken, da diese Momente die Verbreitungsweise mancher Infectionskrankheiten in hohem Grade beeinflussen."—FLÜGGE.

"Exact scientific knowledge of the contagia and of their respective modes of operation is of supreme importance to the prevention of disease. With even such knowledge of them as already exists diseases which have in past times been most murderous . . . . can, if the knowledge be duly applied, be kept in subjection."—SIMON.

§ 1.—*Infection, Infectious Substances and Infectious Diseases*

In order that apple juice shall be fermented by yeast micro-organisms must somehow find access to it. But the normal apple is protected from the invasion of yeast both by its skin—a mechanical or structural defence—and probably also by specific properties of its living cells, which properties, though they are not understood, are recognized and described by the term "vital resistance." The skin of the apple must be broken and vital resistance overcome

before yeast can make its way into either juices or tissues, successfully "infecting" them and producing those changes which we call fermentation. It may even be said that the apple is "hermetically sealed" by its skin, for no sound apple can be infected or fermented by yeast unless its body has been penetrated either by living yeast cells or else, what is yet an open question, by soluble and diffusible products of yeast.

The word "infection" (from *in* and *facere*) signifies "entrance" or, literally, "making into," and in sanitary science it means in the first place, a process, namely, the entrance into a living body, whether plant or animal, of something capable of producing disease. Contagion, as will be explained presently, is only a special kind of infection. The words "infection" and "contagion" are also used, in the second place, in another sense, substantively, — "the infection," "the contagion," — to represent the infectious or contagious material itself. From what has been said in the preceding chapters it is plain that infection of the human body is usually its invasion by parasitic micro-organisms, each specific invasion constituting a specific infection; and the "infectious diseases" are those which are produced by such invasions. The term "communicable" is also much used for this group of diseases. In practice the word "infection," when used for infectious materials, is usually applied to living *materies morbi* capable of growth and multiplication in the body of the infected plant or animal and of transfer from one victim to another. Etymologically speaking, to be sure, it might be applied also to inorganic matters such as metallic poisons, — lead, copper, arsenic, etc., — or to organic but lifeless poisons, — such as the venom of serpents, the vegetable alkaloids, etc., — introduced in any way into the living organism; but as these are doubtless also communicable (though rarely communicated), either term may be used at will, both being clearly inferior in descriptive accuracy to the term "zy-

motic," which, after all, is probably the most correct and comprehensive name for those diseases which are essentially attacks upon the plant or animal body by living ferments. That these ferments happen also to be more or less readily "communicable" is an incident only and not their principal characteristic; and that they are "infectious," or capable of entering the body, is a property which they share with diseases caused by other environmental agencies, such as lightning, arsenic and toadstools mistaken for mushrooms.

§ 2.—*The Skin and Epithelia as Structural Defences of the Living Body against the Invasions of Disease*

As the normal apple is protected by its covering or skin, so the normal living body is protected by its coverings—skin and epithelia—from the invasion of parasitic or fermentative micro-organisms or their products. It is perhaps too much to say that the living body is hermetically sealed, and yet modern physiology teaches that one of the principal offices of the skin is protection against forces or substances acting from without, and that the cells of the more delicate epithelia covering the lung surfaces and the alimentary and genito-urinary tracts have as one of their specific duties a certain discriminating authority over the matters likely to pass through or to be absorbed by them. In somewhat more than a metaphorical sense, therefore, it may be safe to say that the living animal body is hermetically sealed against the invasion of matters proceeding from the environment. The phrase, once much used, which referred to any rupture of this seal as a "solution of continuity" undoubtedly referred to the same idea, and marks the recognition of the essential integrity of the body surfaces as one condition of health.

In order that any germ, whether parasitic or not, shall find entrance into the living body, it must be able some-

how to pass through the ordinary defences. In the case of the skin it would appear that an actual rupture must take place, as happens, for example, in a puncture, incision, bruise or other mechanical injury. In the case of the epithelia, it may be that a similar passage by force is necessary, or it may be that the living cells which here line the surface externally are, so to speak, off their guard or for the time being actually facilitate an invasion which, from their delicacy, is here more easily effected. At any rate, it is easy to see that for the actual entrance of micro-organisms into the body proper an unusual and direct passage must somehow be provided. As to the absorption of the toxic products of germ life we shall have something to say in § 5.

It should not be forgotten that by "the body proper" is meant that portion of it enclosed within the skin and epithelia; the cavities of the alimentary canal and the genito-urinary tracts not being included, inasmuch as they are really portions of the environment merely passing through or dipping into the body-mass.

§ 3.—*Infection by Way of the Skin. Invasion by Force*

The processes of infection by way of the alimentary canal and the genito-urinary tract, to be described in § 5, are typical of a large class of the more obscure infectious diseases. There is, however, another and commoner path by which micro-organisms obtain entrance into the body proper, and that is directly through the skin, the diseases to which they give rise being known as "wound" diseases. Many of these are familiar, as, for example, the results of simple punctures made by small foreign bodies such as pins, needles, "slivers" and the like. When these carry in with them micro-organisms capable of setting up fermentation or inflammation, the infection thus produced may be either local or general: in the former case leading to the condi-

tions familiar in such unimportant local wounds as those mentioned; in the latter to septicæmia, or dangerous blood poisoning, a kind of fermentation of the whole body. Occasionally it happens that a wound made by a sliver or some other ordinarily insignificant object, such as a needle or a bee sting, is followed not merely by the usual local inflammation, but by a far more serious and extensive injury and even by speedy death. It is supposed that in these cases either the infection was of an unusual and severe type — by which is meant that the micro-organisms were unusually abundant or of some unusually virulent species — or else that the vital resistance of the cells and tissues of the victim happened to be poor in kind or at a low ebb, so that even ordinary micro-organisms met with specially favorable conditions. In a word, either the infection was unusually powerful or the patient was unusually susceptible. It is, of course, possible to conceive of a third condition resulting from an unfortunate coincidence or combination of the other two.

§ 4. — *Wounds and the Diseases of Wounds*

The punctures and other simple infections by way of the skin just described belong in the same class with more serious interruptions of continuity such as gun-shot wounds, compound fractures, abrasions and the like, among which must be classified as of the highest practical importance surgical operations such as excisions of tumors, amputations, the tying of arteries, etc. In these cases the bullet, the surgeon's or dissector's knife, or other foreign body of relatively large size, may readily be a vehicle for the germs of infectious disease. It has already been pointed out how the classical inductions of Lister and his application of the germ theory and its corollaries to this class of diseases has led to results of the first importance in this direction, namely, to sanitary or aseptic surgery. (See p. 45.)

There is one disease of wounds particularly interesting, for various reasons, to the sanitarian as well as to the surgeon, namely, *tetanus* or "lock-jaw." It had long been known from observation and experience that certain punctures or incisions, especially those made by the entrance or laceration effected by dirty foreign bodies, were not infrequently followed by a peculiar condition of the patient in which tetanic muscular spasms were a prominent feature, when, in 1884, Neisser isolated from garden soil a bacillus capable on inoculation into mice and rabbits of producing a similar disease. Further investigations have confirmed the discovery, and the natural history of the *Bacillus tetani* is now well known. It is frequently found in the earth and it is widely distributed in nature. It is anaërobic, *i.e.*, it thrives best in the complete absence of oxygen. Cultivated in bouillon, it produces a powerful poison (toxin) which appears to realize the early speculations of Dr. Farr,[1] and which, even in the absence of all living bacteria, is capable of producing typical tetanic convulsions. A substance apparently identical with it has been separated from the muscles of patients dead of tetanus, and this substance, when injected into the lower animals, produces in them tetanic spasms. It may be added that an antitoxin capable of neutralizing the toxin of tetanus has more recently also been prepared and used.

The importance of the bites and stings or other punctures of the skin by insects, which has long been recognized theoretically, has recently received fresh emphasis and attention, owing to the results of investigations upon the hitherto obscure but widespread disease known as malaria. It is now believed that the female of a species of mosquito is the principal vehicle of this disease; that the mosquito becomes itself inoculated by drawing the blood of malarial human subjects in whom the germ of malaria exists, often in the red blood-cells; that in the mosquito the malarial

[1] "Vital Statistics," *l.c.*, pp. 244–245.

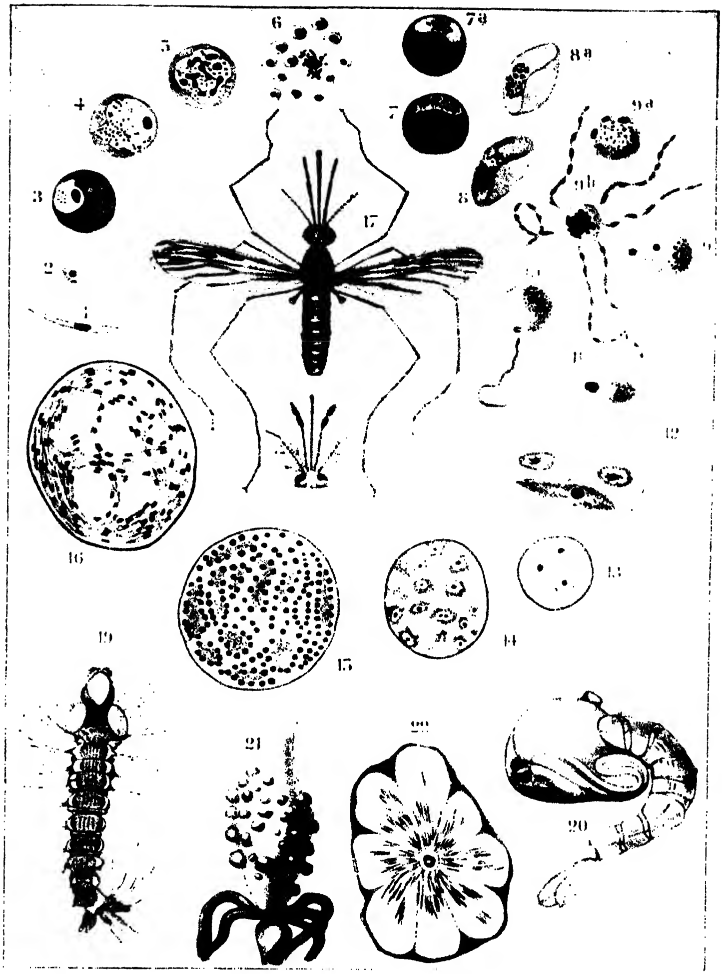


FIG. I. (*After Leuckart-Chun's Wall Diagrams.*) ANOPHELES AND THE MALARIA GERM. 1, 2. The malaria germ (*Plasmodium*) introduced by a mosquito bite into human blood. 3-5. After penetrating a red blood cell, it grows at the expense of the latter. 6. Its vegetative multiplication. 7, 8. Crescentic forms (for further development the germs must at this point be transferred from the man to mosquito). 9. Female germ cell. 9a, 9b. Male germ cell. 10. Conjugation of 9 with one of the vibratile arms of 9b. 11. Malaria germ resulting from such conjugation in stomach of mosquito. 12-16. Multiplication, encystment and sporulation of the malaria germ in the body of the mosquito, with production of many forms like 1 (very much enlarged). 17. Female malarial mosquito (*Anopheles claviger*); head of male below. 19, 20. Mosquito larva and pupa. 21. Stomach of mosquito showing tumors produced by 16. 22. Cross section of salivary gland of mosquito, showing malarial microbes which have wandered into it (from the tumors in 21) and now ready to be transferred with saliva into persons bitten.

germ develops; and that by the mosquito it is injected with the saliva as an inoculation into fresh victims during the bite or sucking of the animal. Dog-bite and accompanying hydrophobic inoculations also plainly belong in this class of wound diseases.

The researches of Laveran, Manson, Ross, Celli and others upon malaria, and mosquitoes as hosts of the malaria parasite, form one of the most brilliant and instructive chapters in the history of sanitary science and experimental medicine. The parasite, which infests the red blood-corpuscles of its victim, had been recognized for several years, but nothing whatever was known of its life outside the animal body or the method of its distribution until it was discovered that the female of at least one species of mosquito (*Anopheles*) is capable of acting as an effective vehicle of the micro-parasites (hæmatozoa).

Further discoveries have shown that the *Anopheles* must itself become inoculated by sucking the blood of a malarial animal; that the parasites undergo an important part of their development within the body of the mosquito (which is therefore a host as well as a vehicle of the microbes); and that they are conveyed to animals bitten by the mosquito with the salivary poison injected during the bite. The mosquito, in short, is an intermediary host, precisely as is the hog in the life-cycle of *Tænia*, the pork tapeworm. The practical importance of these discoveries is immense, for it has already been established by experiment that man may live in "malarious" districts with no risk of contracting malaria provided pains are taken to avoid absolutely all mosquito-bites; and on the other hand, it has been shown that mosquitoes that have bitten malarial subjects may readily transmit the disease by their bites, and infect fresh victims even in regions hitherto absolutely free from malaria.

More recently still evidence seemingly conclusive has been obtained—at great personal risk, and with admirable

courage — by American investigators in Cuba that yellow fever is similarly transmissible by mosquitoes, and not readily, if at all, by infected bedding or other lifeless materials.

Flies have of recent years come to be regarded as ready vehicles of infection, and especially of typhoid fever. Lime scattered over excrements in privies has been observed on the feet and legs of flies running over food set out for eating upon tables in the neighborhood, and if lime can be thus carried, there is no reason why microbes also may not be carried to food or drink. It is also probable that the bites of flies may convey infection, although this has not yet been established. It is believed, however, by experts that one of the principal sources of typhoid fever in army camps is the infection of food by flies acting as vehicles of the microbic infection.

Those who would pursue these subjects further are referred to the following works: Celli, "Malaria according to the New Researches" (English translation by Eyre and an Introduction by Dr. Patrick Manson), Longmans, Green & Co., 1900; Howard, L. O. "Mosquitoes: How they Live, How they carry Disease," etc., New York (McClure), 1901.

§ 5. — *Infection by Way of the Alimentary Canal, Lungs and the Genito-urinary Tracts*

The alimentary canal being in free connection with the environment and really a portion of it, is naturally subject to invasion from various sources by various micro-organisms and similar extraneous matters; and the same thing is true of lungs and genito-urinary tracts, though perhaps in less degree. The alimentary canal, moreover, is ordinarily well stocked with food materials for micro-organisms; and although the gastric juice probably exerts an unfavorable influence upon them, it may be said that, on the whole, the warm and well-fed alimentary canal affords an excellent

breeding-ground for certain bacteria. But if bacteria multiply enormously in the alimentary canal, they do so at the expense of materials found therein, and in the course of their multiplication must produce various substances of the nature either of by-products or excreta; and some of these may conceivably be harmful either to the guardian epithelia lining the alimentary canal or to the tissues in general, if once they are absorbed and distributed by the circulation. Similarly, micro-organisms grow freely within the genital tracts, and feeding upon the exudations or secretions there found may multiply enormously, with the consequent production of deleterious substances which shall damage either the lining epithelia or, when absorbed, other tissues of the body, near or remote. Moreover, in both these cases the paralysis or destruction of the guardian epithelia may produce actual solution of continuity, which shall allow either the micro-organisms in question or their poisonous products to find ready entrance into the body proper.

There is reason to believe that the bacillus of diphtheria, for example, works precisely in this way. Finding lodgment upon the tissues of the throat, it proceeds to grow and multiply upon the normal exudations and the food materials there present, and in the course of its vital activity produces somehow some of that poisonous substance which is now well known as the "toxin" of diphtheria. This first paralyses or otherwise interferes with the normal activity of the cells lining the throat in its immediate vicinity, whereupon, these cells failing to do their duty, an abnormal exudation of lymph takes place, and this, coagulating, produces the well-known "white patches" so common in "the diphtheritic throat." At the same time a powerful poison, the toxin, is being absorbed into the general circulation, and causes those general or constitutional symptoms which are characteristic of the disease.

In the case of Asiatic cholera, there appears to be first

an invasion and then a genuine and extensive fermentation of the contents of the alimentary canal, with an enormous multiplication of the micro-organisms concerned, so that these can readily be detected in large numbers in the bowel discharges. At the same time the characteristic poison or toxin of Asiatic cholera is supposed to be liberated, and its absorption through the walls of the alimentary canal is supposed to give rise to constitutional symptoms characteristic of the disease and indicative of profound disturbance of the body proper, such as vomiting, fever, sweating and delirium. In these cases, as will be observed, it is not the germs themselves, at least in the first place, which penetrate into and ferment the body itself. It is rather by attacking the frontier, there and then setting up their own peculiar fermentations, and producing poisons which are easily absorbed, that these micro-organisms first do their harm and open the way for themselves or other germs to enter into the body proper. Nevertheless the process, even from the very start, is one of fermentation, directly affecting either the body wall or materials, such as partially digested food or secretions, closely connected with and for the time being practically a part of it. (Cf. § 3, p. 92.)

§ 6. — *The Physiological Defences of the Living Body. Vital Resistance and Susceptibility once more*

The term "vital resistance" has been much used in the last few sections, coupled with the statement that its exact significance is unknown. It is unnecessary to argue again at this point that there is such a thing as vital resistance, or that it varies largely from time to time. The experience and observation of everyday life abundantly testify to these facts. Who has not witnessed, for example, that robust and abounding health which enables some persons to live happily and carelessly in poverty, filth, and squalor, while

others, surrounded by every comfort and protection, perish on the least provocation? Again, who has not, even in himself, known times when almost anything might be done with impunity, and other times when the least exposure or other unfavorable condition led to indisposition or illness? Who has not remarked over and over again the immunity of youth, the fragility of age? In no other way than by recognizing differences in resistance to unfavorable environments can these anomalies be explained, and the term "vital resistance" well sums up and describes facts established by the long and accumulated experience of the race. It describes the facts, but, as so often happens with terms applied to human experience, it does not explain them. Sanitary science, however, gladly accepting and using the terms "vital resistance" and "susceptibility," — the latter being the converse of the former, — seeks to go further and learn, if possible, the causes of these conditions, and the processes by which they are reached. It must be frankly admitted that thus far the search has not been wholly successful, and yet something has certainly been done, at least toward making things clearer and more comprehensible. (Cf. pp. 74–85.)

It is easy to see that "vital resistance" must be largely constitutional. It must depend either upon the materials of which the body is built or on the way in which these are put together, or, more likely, upon both. In order to resist the attacks of micro-organisms upon epithelial surfaces; or to overcome them on their arrival if thrust in by force through the skin, as happens in wounds; or in order to neutralize their poisons (toxins) if these succeed in breaking down and passing through the epithelia or the skin, mechanical and chemical defences within the body — physiological defences — would seem to be most useful; and it is therefore interesting to find, as we do, that the modern theories of "vital resistance" (which in its most perfect form is now called "immunity") proceed along these lines.

A little reflection will show that micro-organisms on entering the body or any of its passages are immediately subjected to a peculiar environment, which for many species must be highly unfavorable. This may be said to be the simplest of the physiological defences. The first of these met with may be the gastric juice, which for many microbes is highly unfavorable on account of its acidity. The comparative immunity of plants to bacterial diseases and their relative susceptibility to the attacks of fungi has been accounted for in part on the ground of the greater acidity of their juices. Those microbes known as "disease germs," on the other hand, must be supposed to find the new conditions more or less favorable; more if the patient is susceptible; less if he is endowed with considerable vital resistance; wholly unfavorable only if he is immune.

Even milk, which is well known for its blandness and as a favorable culture medium for many bacteria, being literally crowded with certain species when it is stale, has been described as "germicidal,"[1] so that the first and very likely the most important physiological defence of the living body may be the fact that merely as such it furnishes an unfavorable environment for many invading organisms. The bodies of micro-organisms perishing in the invaded territory, whether this be local or general, in the healthy animal soon disappear, and there is reason to believe that they are removed by the white corpuscles of the blood and the lymphatics, acting as scavengers. Whether these devouring cells (phagocytes) are soldiers as well as scavengers, whether or not they can kill as well as devour invading micro-organisms, is not wholly clear. The view that they can and do, and that acquired immunity depends largely on their training so that they shall do it successfully (Metschnikoff's theory of immunity by "phagocytosis"), while it has developed many interesting facts (as stated

[1] "Ueber die Bakterienvernichtenden Eigenschaften der Milch," Baumgarten's *Jahresbericht ueber Mikroorganismen*, VI. 513, 529.

above), seems somewhat too picturesque and too anthropomorphic. It is not much easier to understand with Behring and Roux how the cells of the tissues or the blood after one attack of an infectious disease, such as diphtheria, are so "affected" that they secrete regularly thereafter and in its absence a chemical antidote for the diphtheria toxin.

Perhaps the truth is to be found in a combination of these various views. The physiological defences may very likely consist in (1) the fact that the living body merely as it stands offers to many micro-organisms an unfavorable environment for their normal development; (2) the fact that some microbes on entering are seized and devoured by phagocytes drawn to them by chemiotactic influences; (3) the fact that over and above the general unfavorableness of environment, immune animals possess somehow, either naturally or acquired, the faculty of subjecting special invaders or their products (toxins) to the action of special chemical substances (antitoxins) which destroy their efficiency.

It will be observed that in all these cases the defence consists essentially in a kind of internal or physiological disinfection, which whether real or not is conceivable enough. But besides this we have to recognize the fact that the living cells of the epithelia appear to have a certain power of "selection," at present not understood, Doubtless this is no more mysterious than, for example, that power of selection which the absorbents appear to exercise, or that property of the cells of the stomach or intestine by virtue of which they are not digested by their own juices respectively. The fact, however, remains at present essentially unexplained.

§ 7. — *The Precise Meaning of Contagion*

The terms "infection" and "contagion" as applied to processes rather than substances (for in the latter case

they mean exactly the same thing) may now be further defined and explained. The former, strictly speaking, signifies "entrance," the latter "contact." Though often used as if synonymous, they are not best so used. Infection is the broader and larger term, and includes contagion. It signifies simply the entrance or "making into" the body of harmful material. This may be either living or lifeless, but the term is generally applied to the entrance or making in of living organisms by any method or avenue whatsoever. Contagion, on the other hand, is only a particular kind of infection of living organisms or microbes in which the infecting substance is transferred from source to subject by direct contact, as, for example, when the contagion or infection of small-pox is derived by the victim directly from contact with a preceding case. Infection is well illustrated by cases of typhoid fever or Asiatic cholera in which the bowel discharges of a person, A, find access to water or milk and are consumed with food or drink by another person, B. In this case B may never have seen, or heard of, or been anywhere near, A, and there may have been no contact whatever between them. In a word, contagion is direct, immediate — and generally personal — infection, while other forms of infection are more or less roundabout and indirect. Contagion operates, nevertheless, in precisely the same way as infection. In all cases whether of infection or contagion there must be somehow a transfer of infectious material more or less directly from an antecedent or primary case as a cause, to a consequent or secondary case as an effect; and it matters not, except as to details, whether the infectious material is derived immediately from the antecedent case by actual contact with it, or after the lapse of a long time and in obscure and roundabout ways. Both phenomena belong in the same category, though the more obvious is called "contagion" and the less obvious "infection." It would be better to drop altogether the term "contagion," and to

apply to all these cases the simple and accurate term "infection,"[1] which, if we neglect the idea of entrance by force, has almost exactly the same significance as "invasion," and corresponds precisely to the popular term often applied to infectious disease, namely, an "attack."

§ 8. — *Man and Other Animals the Principal Primary Sources of Infection*

We have now considered somewhat briefly the portals of entrance of infectious materials into the body proper, and have hinted at some of the vehicles of infection. Before dwelling long upon these it will be well to consider the original sources of infectious materials in the environment. Once we have determined the sources of infections, it will be comparatively easy to discover the avenues of communication and the vehicles by which they travel.

It was formerly supposed that the earth and various other non-living materials were prolific original sources of infectious disease, or in other words, that the germs of disease not only exist but thrive and multiply in the earth. It was thought, for example, and is still held by some, that the micro-organism of typhoid fever passes a portion of its life and undergoes a necessary portion of its development in the soil, especially in filthy soil, and similar ideas were held in regard to other infectious diseases. Doubtless the reason for this opinion was to be found in the fact that certain animal and vegetable parasites had been known for a long time to spend one portion of their lives in or upon some plant or animal other than, and often lower than, their most conspicuous host. This is true of the tapeworm, the *Trichina*, the blight of barberries, and many other para-

[1] Much confusion in the use of these and related terms exists in the works of the earlier authors. Even Dr. Farr (*l.c.*) refers to "diseases propagated either by inoculation and contact (contagion) or by inhalation (infection)," and says "miasms produce diseases like ague, without being propagated by contagion."

sites. The progress of inquiry, however, has not confirmed these ideas, except in special cases (such as that of *tetanus*, p. 94), for the ordinary infectious diseases. It has been said that some still hold to the idea in the case of typhoid fever; but the author believes, after a very considerable investigation of the question, and personal studies of epidemics which he has had somewhat unusual opportunities to witness, that this idea is not sound, and that every case of typhoid fever, at least in the latitude of New England, arises rather directly from an antecedent case, and in this way only. It is, of course, possible that in other latitudes, and under conditions particularly favorable, the typhoid bacillus may grow outside the human body. There is no question that under favorable conditions it can do this in laboratories; but that it does so in nature in temperate climates, except under very unusual circumstances, does not seem to be indicated by the evidence at hand. It can unquestionably *live* for some time in nature, though apparently with diminishing virulence, and in diminishing numbers; but in northern latitudes and under ordinary conditions its prolonged survival, and especially its multiplication outside the body, must be doubted.

A similar statement may be made in the case of many infectious diseases, and we may safely say that for the most part man and other animals are the original sources of infectious disease. But it should always be remembered that under tropical conditions, if only suitable food and moisture be present and other conditions favorable, the germs of infectious disease may live long and actually multiply outside the animal body.

Since the above paragraphs were written the amazing revelations of the rôle played by mosquitoes in the conveyance and the development of malaria have been made. From these it appears that here also a disease long associated with swamps and mysterious "miasms" has its sources

only in animal bodies, for the malarial parasite comes from the bodies of men and mosquitoes, which thus appear to be the only original sources of infection.

§ 9.—*Man and Other Animals, and especially their Excreta, the Principal Primary Vehicles or Prime-movers of Infection*

If it be true that man and other animals are the principal original sources of infection, it must follow as a matter of course that their excreta are its principal original vehicles; for the excreta represent the output of the organism, its contribution to the environment. Physiology teaches that the material output of the animal body consists of discharges from the alimentary and genito-urinary passages and from the skin,—the nose and lungs being regarded as branches of the alimentary apparatus,—and accordingly it is these discharges which must be the principal original vehicles of infectious disease from its place of origin to the environment. Diseases have, in the past, often been roughly classified according to their place of origin and the vehicles by which they are conveyed. An important class of infectious maladies known as "diarrhœal" diseases is directly attributed to infections from the bowel discharges. Typhoid fever, Asiatic cholera, dysentery, diarrhœa, and cholera infantum are the most important members of this class. Of equal or even greater importance are those diseases known as "eruptive" diseases, which are readily scattered from seedings of the shed-off skin. In these cases, pustules form on the skin and, opening to the exterior, discharge their secretions there. To this class belong some of the worst diseases that afflict the human race, such as small-pox, typhus fever, scarlet fever, measles, chicken-pox and many more. Since the infectious material is in this case poured out upon the surface of the body, it is readily transferred by direct contact to the fingers, and thereby to the mouths or, when dried,

by the wind, to the noses and lungs of other persons. Hence, the term "contagious" diseases, especially applied to this group. Again, a certain number of diseases affecting the mouth, throat, or lungs may be conveyed by means of the sputum or saliva thrown out of the mouth and eventually finding its way either when dried, pulverized and blown about by the wind, or through the agency of food contaminations, to other susceptible persons. In this group would naturally be found diphtheria and pulmonary tuberculosis.

The other excreta, such as the urine and the breath, as well as the sweat, are not usually charged to the same extent with the carriage of disease. The expired air from the lungs, formerly so much dreaded by those who watched at the bedside, appears according to the careful investigations of bacteriologists to be the least dangerous of all the excreta, being practically germ-free. The reason for this is that the moist, spongy lungs act as an efficient filter, and not only refuse to yield up micro-organisms to the expired air, but even detain organisms arriving in the inspired air, so that the outgoing breath of a patient is from the bacteriological point of view actually purer than the inspired air. Recent researches, on the other hand, have shown that the urine may be a ready vehicle of the microbes of typhoid, and very likely of other, fevers.

It is interesting to note, also, that the malarial parasite passes from mosquito to man with an excretion, the saliva. From man to mosquito it does not pass in this way, but rather as a contamination of stolen food, the sucked blood being itself infected.

§ 10.—*Earth, Air, Water and Animals the Principal Secondary Vehicles of Infectious Disease*

But if the excreta are the principal original vehicles of infection, they are by no means the only vehicles, for they

may readily mingle with and transfer their burden of infection to almost any substance in the environment. From the skin the surrounding air may first become infected and then move on, laden with disease, so that disease — or rather its germs — may literally be borne on "the wings of the wind." Likewise, sputum from the mouth, or discharges from the bowels, may be imperceptibly mingled with a stream, so that a cup of cold water — the time-honored symbol of purity and charity — may contain unseen and unsuspected the germs of deadly or disgusting diseases. Or, again, the earth impregnated with human excreta may be dried and pulverized, and, as dust infecting human throats, become the vehicle of diseases such as diphtheria or tuberculosis. Clearly, if animal life is the principal source of infection, and the excreta of animals are its principal vehicles, these, being some solid, some liquid and some gaseous, are only too likely to find kindred substances in the environment with which they can mingle, and to which they can convey a portion at least of their burden of infection.

We have already seen how insects may become the bearers of infection, and we may now turn, in the following chapters, to a detailed consideration of several other of the most important and most common vehicles of infection, namely, dirt, dust, air, sewage, water, ice, milk, raw foods (such as oysters and salads) and the like, and the ways in which these can be protected or purified.

CHAPTER VI

ON DIRT AND DISEASE. THE LIVING EARTH. DIRT, DUST AND AIR AS VEHICLES OF INFECTION. FILTH, FILTH DISEASES AND THE PHILOSOPHY OF CLEANNESS

"Uncleanness must . . . be reckoned as the deadliest of our present removable causes of disease." — SIR JOHN SIMON.

"Cleanliness covers the whole field of sanitary labor. It is the beginning and the end." — DR. B. W. RICHARDSON.

THE experience of the race has shown that one of the most effective vehicles of disease is dirt. The word "dirt" appears to be derived from an old Saxon word *drit*, meaning *excrement;* but the modern form of the word "dirt" has taken on a more extended and less definite meaning. As ordinarily used it may be the synonym of dust, soil, filth or almost any form of uncleanness, whether such uncleanness imply the presence of infection or only that of pollution. Still it can hardly be denied that even at present the word "dirt" signifies something distinctly more filthy than do the words "earth," "soil" or "dust." It is easy to see in the origin of the word the reason for this, and after what has been said in the preceding chapters concerning the primary sources of infection and the efficiency of excrement as a vehicle, no surprise need be felt that dirt is regarded with suspicion by all intelligent and well-informed persons.

§ 1. — *Clean Earth and Infectious Dirt*

Unquestionably the general fear of dirt among the intelligent is not in all cases discriminating. "There may be,

and probably are, forms of dirt which carry with them very little of danger, and a certain recognition of this fact is shown in such expressions as "good clean earth." It appears to be true that while it is the earth that is most often associated with the idea of dirt, it is ordinarily only the surface of the earth which is thus looked upon with suspicion and aversion. One reason for this probably is that the surface or loamy layers of the soil are not infrequently sticky and suggestive of organic matters, while the subsoil directly below the loam layer is generally more obviously mineral in its character and often clean, *i.e.* not sticky or "dirty." As a matter of fact the loamy layer so called is, in truth, richer in organic matters, and besides often containing innumerable earthworms is crowded with the bodies of micro-organisms. The earthworms by their ploughing actions, which Darwin has so admirably worked out, are constantly turning over the upper layers of the earth, carrying from the surface into the lower strata organic matters, and from below to the surface the more mineral subsoil. It follows, therefore, that not only is the surface of the earth contaminated by excrement of various kinds that falls upon it, but also, through the agency of earthworms, a considerable portion of the earth just below the surface, and especially, no doubt, the loamy layer already referred to.

Accordingly, if we desire to define and classify the terms already used, we shall say that *earth*, broadly speaking and for the most part, is essentially mineral in character and clean in condition because free from any considerable amount of organic matter. It is also, therefore, ordinarily free from infection—uninfected as well as unpolluted. *Soil*, *i.e.* the surface layer of the earth, may be clean, and may be and ordinarily is fairly free from infectious materials, but inasmuch as it is exposed to contamination by dirt, *i.e.* excrement, and is being continually worked over by earthworms, it may be and usually is more or less

polluted or contaminated with organic matter. It may or may not be infected. *Dirt* in the original and most exact sense is simply excrement, but in the more ordinary use of the word is *soil*, *i.e.* the surface layer of the earth, which may or may not contain infectious materials.

§ 2.—*The Living Earth*

It is one of the most marvellous revelations of bacteriology that the earth, long regarded as the type of lifelessness, is in fact, at least in its uppermost layers, teeming with life. Not only do many mammals, birds, reptiles, insects, and worms have their homes in the earth, but, as bacteriology teaches, also vast hosts of micro-organisms, more abundant by far than the grains of sand upon which they dwell. A single gram of garden soil may contain millions of micro-organisms, and much of the softness and stickiness of moist loam is probably due to the presence of such numbers of soft protoplasmic bodies. Thus it has come to pass that we are no longer at liberty to speak or think of the earth, at least in its upper layers, as dead and essentially mineral, but must regard it instead as highly organic and quivering with life.

§ 3.—*Earth as a Vehicle of Disease. Tetanus or Lockjaw once More*

The earth is not only rich in germs, but may contain among these some that are pathogenic or disease-producing. Reference has already been made to tetanus as caused by specific microbes found in the soil (pp. 94, 104), and these are especially interesting, inasmuch as they appear to lead regularly a saprophytic rather than a parasitic life. In this respect we have reason to suppose that they (and a few others) differ from most pathogenic microbes, which fortunately do not, under ordinary con-

ditions, appear to thrive (though they may continue to live for a long time) outside the plant or animal body.

§ 4.—*Dust and Disease*

Dust is pulverized soil or pulverized dirt, and only rarely pulverized and pure earth. It is therefore, as a rule, rich in bacteria, and may or may not contain infectious disease germs. Inasmuch as it is the surface of the earth which is ordinarily dried, pulverized and lifted into the air, it is easy to see that excrement of any kind, deposited upon the soil, sputum and other organic matters cast off by animal bodies,—such as scales from the skin, bits of hair, dandruff and the like,—as well as the possible combination of all these things with dirty water to make sewage, may when dried on the surface of the earth be also readily pulverized and lifted into the air as fine particles or motes of dust. At first sight, dust of this character might be supposed to be necessarily dangerous and even deadly, and there is very little doubt that infectious diseases are in fact frequently transmitted by dust which serves as a vehicle; but, on the other hand, it should not be forgotten that there are certain compensating circumstances which tend to diminish the dangers of disease from this source. The unfavorable conditions to which micro-organisms are exposed in dust, namely, desiccation, possible germicidal action of light, unfavorable temperatures and the like, undoubtedly destroy many of them and weaken others, but, in spite of these various fortunate conditions, it still remains true that dust must always be regarded by the sanitarian as dangerous, not only because of the mechanical irritation of the delicate mucous membranes of the throat and other respiratory passages caused by the inorganic particles of which it is largely composed, but also because of the possibility of its containing virulent disease germs, such as those of tuberculosis of diphtheria

from the sputum of persons affected with these maladies; as well as those of small-pox, scarlet fever, measles and the like, from the skin-scales of victims of these diseases; and, to a less extent perhaps, the germs of typhoid fever and other diarrhœal diseases from the pulverized excreta of walking cases, or from night soil spread upon fields for manure and afterward dried and lifted into the air by winds during the operations of hoeing, harrowing, ploughing and the like.[1]

§ 5. — *The Atmosphere as a Vehicle of Disease; Ancient and Modern Theories*

From the earliest times the atmosphere has been regarded with suspicion as a vehicle of disease. Miasms, pestilential vapors and various mysterious and unseen influences have been regarded as readily conveyed by the atmosphere, and obscure or occult effects not comprehended or else misunderstood have been attributed naturally enough to the omnipresent and always-moving atmosphere. It is one of the merits of the germ theory of infectious disease that it enables us to comprehend much more clearly than ever before the true nature of these supposed atmospheric influences. From what has just been said in the last paragraph, it is easy to see that the atmosphere may under certain circumstances be a ready carrier of infectious disease simply by serving as the vehicle for the floating organic matters and living particles which are lifted into it from the surface of the earth or from human bodies. Doubtless it is with these very much as it is with the birds of the air or the flying fish of the sea, which, caught up or springing from the earth or the sea, may for a longer or shorter time float, fly or swim in the atmosphere, but which after all belong

[1] Those who wish to pursue this subject further may consult with advantage Tyndall's "Essays on the Floating Matter of the Air," New York (Appleton), and Prudden's "Dust and its Dangers," New York (Putnams).

to the earth and sooner or later return to it. It must not, however, be forgotten that the germs of the commoner contagious diseases, and especially of those known as "eruptive," in which "peeling" of the skin occurs, may be and probably are often disseminated through the atmosphere, and that so much of truth existed in the primitive ideas of mankind.

§ 6.—*Microbes of the Air*

The number of microbes in the atmosphere varies greatly.[1] In a dust-storm five feet above the surface of a macadamized street the author and one of his pupils, Mr. (now Dr.) John A. Rockwell, Jr., detected in ten litres of air two hundred thousand micro-organisms. Quiet air is usually relatively free from them (sewer air, for example, being often nearly or quite destitute of microbes), and the same is true of the atmosphere at high altitudes and in mid ocean. Even the expired air of the human lungs is quite free from germs, a fact doubtless due to the spongy and moist pulmonary surfaces which catch and detain incoming microbes and a phenomenon of great interest and importance in the theory of infection.

It is impossible to conceive of any other source or sources of infectious disease in the atmosphere than microbes. On the other hand, there is no difficulty in supposing that the ground air, rising and mingling with the ordinary atmosphere, especially in periods of low barometer; the gaseous exhalations of marshes, volcanoes, and the like; the results

[1] The presence of microbes in the air is easily demonstrated, and their number enumerated, by various methods described at length in works on bacteriology. One of the simplest methods is that devised by the author and Mr. (now Professor) G. R. Tucker. It consists in filtering a known volume of air through fine sugar or sand—the latter having been found by experience to be preferable—by means of an exhausted cylinder and a glass tube of special form, called an *aerobioscope*, capable of being converted at will into a "roll" tube. The micro-organisms are held back by the sand, and together with the latter are mixed with melted gelatin during the rolling process and afterwards incubated, cultivated, enumerated and studied.

of decomposition of dung-heaps, filth and other masses of decaying organic matter may, under certain circumstances, act as unfavorable environmental conditions and reduce the vital resistance to such a point that disease, which would otherwise have been absent, occurs. This simple view probably includes all or nearly all of the facts relating to the atmosphere, strictly so called, as a source of disease, and probably suggests the true explanation of diseases supposed to be due to miasms, pestilential vapors, atmospheric and telluric influences, and the like. Even malaria, which has long been a puzzle to sanitarians, is apparently due not to any peculiar evil quality or disturbance of the atmosphere, such as the word implies, but rather to specific micro-organisms conveyed by the latter either directly as floating particles, or indirectly through insects or other living agents of transmission moving in or through the air (see pp. 94–96). Malaria has often been called *paludism* or swamp fever; but if the modern view is correct it is not swamp air, but swamp insects (mosquitoes), which under favorable circumstances transport the germs of *paludism*.

§ 7. — *Filth Diseases. The Pythogenic Theory. Modern Views of Filth and Filth Diseases*

The principles which have been laid down in the preceding chapters enable us to take up with regard to filth diseases a somewhat different view from that held in the third quarter of the nineteenth century. The term "filth diseases" was at that time used with the idea that filth might be not only a vehicle, but an actual breeder or generator of infectious disease. This view even reached the dignity of a theory bearing a special name — the "pythogenic" theory, — which is closely associated with the name of Murchison. According to Murchison, filth was dangerous not merely because it was a vehicle of disease, or an

unfavorable condition, but also because it was a *source* of disease, the supposition being either that specific disease germs could be generated *de novo* from other germs in filth, under favorable circumstances, or that at least germs capable of producing disease found in filth the conditions for their more perfect development, some even requiring residence for a time in filth in order to reach their full maturity. In regard to typhoid fever, for example, it was held that the micro-organisms of the disease required a stay, longer or shorter, in the earth or heaps of filth, and only after such a period attained their natural and dangerous development. The older treatises on typhoid fever and the older teaching often referred to a residence in the earth as one phase in the ordinary development of the germs of typhoid fever.

The pythogenic theory requires some consideration at this point, as it lies at the basis of much popular misconception of the origin of infectious disease and, by misleading, causes a neglect of the true sources of disease. It was first propounded by Murchison in a footnote to a paper read before the Royal Medical and Chirurgical Society of London, April 27, 1858 (*Med. Chirurg. Trans.* 1858, p. 221): "In the course of this essay I shall bring forward what I consider positive proofs that this fever [typhoid] is produced by emanations from decaying organic matter, and I would therefore suggest for it the appellation of pythogenic fever — πύθογενής and γεννάω."

Murchison's views were urged at great length and with much plausibility in the first edition of his work (1862) on continued fevers, in which occur statements like the following: "Pythogenic [typhoid] fever is often generated spontaneously by fæcal fermentation" (p. 455).

The doctrine was vigorously criticised and opposed by the "contagionists," especially by Dr. William Budd of Bristol, and in the second edition (1873) of Murchison's "Continued Fevers" was considerably modified and restricted, although we find in that the following definition of pythogenic [typhoid] fever: "An endemic disease generated and propagated by certain forms of decomposing organic matter" (p. 417). And again: "It may be generated independently of a previous case by fermentation of fæcal, and perhaps other, forms of organic matter. It may be communicated by the sick to persons in health, but even then the poison is not, like that of smallpox, given off

from the body in a virulent form, but is developed by the decomposition of the excreta after their discharge. Consequently an outbreak of enteric [typhoid] fever implies poisoning of air, water or other ingesta with decomposing excrement."

In these statements it is easy to see that Murchison was a believer in the spontaneous generation of specific disease in or through filth, an idea unfortunately still widely prevalent, but wholly without foundation in fact. In regard to a closely related infectious disease *typhus* (jail fever, ship fever, spotted fever), which has often been attributed to filth as a source, whereas filth is probably only its efficient vehicle, Murchison went even further, asserting its spontaneous origin in such conditions as overcrowding and bad ventilation : "Typhus, the grand predisposing cause to which is destitution ; while the exciting cause or specific poison is generated by overcrowding of human beings with deficient ventilation" (*Edin. Med. Journ.*, 1858, p. 322).

The modern theories of filth and its dangers are very different from these. Filth is first and always a convenient vehicle of disease; but as a rule, in temperate climates, it is probably nothing more than this unless it be also a depressing, or unfavorable, "predisposing" condition. The earlier view which saw in filth a necessary phase in the life-history of certain infectious micro-organisms is now abandoned, and it is to-day very doubtful whether the germs of most infectious diseases ordinarily find accumulations of filth suitable for their multiplication. There is no question that the micro-organisms of disease may under favorable conditions occur or survive for a long time in filth, and it is probable that under certain conditions of warmth, food-supply and the absence of enemies they may even multiply; but it appears probable that such conditions do not often occur in nature, unless perhaps occasionally in tropical countries. The most natural and the most favorable means for the conveyance of disease germs appears to be that which is quickest and most direct, namely, contagion, or the transfer directly from one individual to another without the interposition of the earth, the atmosphere or other extraneous influences. Contrary to Murchison's view, the longer the journey, and the more the time spent in making the jour-

ney, from patient to victim, the less is the likelihood of the successful transmission of the disease. The interposition of filth or earth or air or water doubtless tends in most cases to the diminution of danger, owing to the unfavorable conditions of one sort or another encountered by the germs *en route*.

Filth is looked upon by the sanitarian of to-day, therefore, as dangerous chiefly because it may contain the more or less attenuated germs of disease, and not so much as formerly because it may be a "breeding-place" for such germs. It is a vehicle rather than a source; and when it is pulverized it may cause an atmosphere in its vicinity to become infected; or when handled it may find its way to the mouth, or when occurring upon fruits, vegetables, in milk, in water or any other substances likely to enter the mouth without having first been sterilized, — and in all these cases it is obviously dangerous as a vehicle.

With these views of filth and its sanitary significance the older notions of "filth-diseases" have faded away. Those diseases to-day are simply ordinary, zymotic (infectious) diseases in which the vehicle of the causative germs is filth of some sort.

§ 8. — *The Philosophy of Cleanness*

From what has now been said, it is easy to perceive the modern philosophy of cleanness. Dirt is dangerous, not because it is "of the earth, earthy," but because it is too often "*drit*" or excrement; and the love of cleanness or the abhorrence of dirt, which is gradually becoming established in all highly civilized peoples, is doubtless a resultant of the dearly bought experience of the race, which has shown that dirt is dangerous and therefore to be dreaded. Cleanness, or the absence of dirt, is not merely an æsthetic adornment, — though doubtless an acquired taste; it is above all a sanitary safeguard, the importance of which

has been learned by hard experience. In other words, to be clean is, in a measure, to be safe from infectious disease; and cleanness applies not only to the person but extends also to the personal environment, and especially to the food supply, the water supply, the milk supply, etc.

Probably, the greatest sanitary step ever taken by the race was the application of high temperatures to the preparation of food, *i.e.* cookery. There is very little doubt that far more important than any increase in the digestibility of food effected by cookery is the destruction of parasites, visible and invisible, within it thus brought about. Charles Lamb was probably right in attributing the love of cookery to the improvement in the flavors of food which it occasions, as is described in his well-known version of the discovery in the case of roast pig; and yet there is every reason to believe — as has only lately become recognized — that the sanitary improvement wrought by the discovery of cookery was even more important than either the gustatory or the nutritive improvement. It is difficult to see how infection could have been otherwise than very common and very disastrous before the invention of cookery, for even to this day uncooked food forms one of the principal vehicles for the conveyance of parasites and disease germs.

§ 9. — *Personal* versus *Public Cleanness*

It follows as a matter of course that personal cleanness is more important than public cleanness. In other words, that the avoidance of personal filth is far more necessary than, for example, is cleanness of streets, dooryards, alleys and the like. And yet, as is pointed out and emphasized beyond (p. 221), public supplies are public dangers. If the public water supply, for example, be infected, no matter how scrupulously clean the residents of a city may be in respect to their persons, they will run very serious

risks of disease if they drink from it. The same thing may be said of the public milk supply; and nothing is more impressive to the practical sanitarian than to witness an epidemic of typhoid fever in a wealthy and well-cared-for quarter of a city, where the inhabitants are personally clean, the houses are unexceptionable, the plumbing perfect, the drains in good condition, the tableware and linen spotless, and yet typhoid fever is present perhaps in nearly every family, because of a polluted and infected milk supply or water supply. It must never be forgotten that the sanitary chain is no stronger than its weakest part, and that, no matter how clean and wholesome all other conditions may be, if there is one point from which the germs of infectious disease may find admission into the body, danger may be imminent. Nothing is more instructive than to discover cities or towns in which great complaint is made of filth in the streets, — from which, after all, comparatively little danger is likely to come, — while an impure water supply or milk supply is being used with absolute confidence, or blindness, or ignorance.

§ 10. — *Public Drinking-cups and their Dangers*

It not infrequently happens that the same persons who complain loudly and rightly enough, perhaps, of dirty streets, and are quick to blame public officials for their laxity in this respect will, nevertheless, at fountains, in railway trains or in theatres, apply their own lips to public drinking-cups which a few minutes before have been touched by the lips of strangers, possibly suffering from infectious diseases, such as tuberculosis or diphtheria. It should require only a moment's consideration to show how great is the risk run under these circumstances, and how inconsistent is the criticism bestowed by one who thoughtlessly takes these grave risks when he cries out at the relatively remote dangers of dirty streets. What has been

said about drinking-cups applies obviously to communion-cups, "roller" towels, razors in barber shops, unclean dishes, spoons, etc., and requires no further comment. The dangers of these things are too obvious to need emphasis. A sanitary fountain has been devised, and is in use in many places, to do away with the public drinking-cup, and in so far as it is successful in doing this, it deserves the warm commendation of sanitarians. The arrangement by which this is accomplished is very simple; and for use in public places, schools, institutions and the like, it promises to be of great assistance. No cup whatever is required, but any one who wishes simply leans over and drinks from a little fountain provided for the purpose. Every instant, of course, the water supply is changing, and if infectious micro-organisms should be for an instant deposited by A, they are necessarily the next instant washed away before B can come in contact with them. It has long been the custom in certain factories abundantly supplied with water, to keep rising, in the middle of a basin of convenient height, a small jet of water, from which the thirsty might drink. Small fountains of this kind can easily be arranged in many public places, doing away altogether with the common drinking-cup, which, wherever found, is a sanitary abomination.

§ 11. — *The Disposal of Dirt, Dust, Garbage and Refuse*

From the point of view of the sanitarian the disposal of garbage and refuse is largely a question of engineering. By "garbage" is usually meant the more solid organic wastes of the kitchen, the more liquid wastes being discharged through the sink-pipe into the sewer. By "refuse" is meant household wastes such as dirt, ashes, papers, boxes, dust, bottles and the like, which are only in part combustible. It is from the sanitary point of view desirable to get rid promptly and effectually of both garbage

and refuse, for these may contain the germs of infectious disease, and their destruction or disinfection by fire—the quickest and most certain of all disinfectants—is highly desirable. What is not desirable is that garbage should be fed to cows used as sources of milk supply, not because of the dangers of infection, but because of the poor quality of milk likely to result. There is less objection, if any, to the disposal of garbage by feeding it to swine, or by carrying it to sea or by ploughing it into the living earth, which latter readily disposes of it as of stable manure. Various methods for the disposal of garbage and refuse are in use; but while cremation, for the reasons given, is undoubtedly the most desirable, the sanitary aspects of the matter do not appear to be especially important so long as garbage and refuse are removed from dwellings or groups of dwellings, such as cities, and somehow effectively disposed of. Those who desire to enter further into this subject may be referred to Chapin's "Municipal Sanitation in the United States," Providence, R. I., 1901; to Goodrich's "Disposal of Town's Refuse," N. Y. (Wiley); London (P. S. King), 1901; and to Baker's "Municipal Engineering and Sanitation," N. Y. (Macmillan), 1902.

§ 12.—*Cleanness, Asepsis and Antisepsis*

Inasmuch as dirt is richly laden with micro-organisms, the agents of fermentation, putrefaction and decay, it is plain that the absence of dirt, or cleanness, must go far to prevent these processes. It is clear, for example, that punctures of the skin made by instruments absolutely free from organisms cannot convey infection; that the knife of the surgeon if absolutely clean cannot cause "dissecting wounds"; that cookery of foods must tend to defer their decay: in short, that absolute cleanness is equivalent to asepsis, and partial cleanness is an antiseptic corresponding in efficiency to its extent. This is now so fully recognized that dirt is to-day regarded as the principal foe of

the surgeon; and probably the cleanest rooms that have ever been known either in modern times or in the past, are the operating rooms of the hospitals of to-day.

In certain industrial pursuits experience is teaching a similar lesson. By drawing milk from healthy cows with extreme precautions as to cleanness, it is possible to have it keep sweet (if refrigerated) during the whole period of a trans-Atlantic voyage. Various other dairying processes are also favored, if not conditioned, by cleanness; canning and preserving are far more successfully carried out if done with scrupulous regard for cleanness; and it is no exaggeration to say that in all human affairs cleanness — which means the exclusion or destruction of germ life — is the keynote of successful sanitation.

CHAPTER VII

ON SEWAGE AS A VEHICLE OF DISEASE. ITS PROPER DISPOSAL AND PURIFICATION. THE NATURAL PURIFICATION OF SEWAGE BY FERMENTATION AND THE LIVING EARTH

"If we neglect this subject, we cannot expect to do so with impunity." — MICHAEL FARADAY, on "The Filth of the Thames." London, 1854.

"The sewer . . . is, so to speak, the direct continuation of the . . . intestine." — WILLIAM BUDD, on "Typhoid Fever." London, 1873.

"The bills of mortality are more obviously affected by drainage than by this or that method of practice." — OLIVER WENDELL HOLMES, on "Border Lines of Knowledge," etc. Boston, 1862.

§ 1. — *The Disposal and Disinfection of Excreta*

SINCE there is reason to believe, as has been shown in Chapter V, that the excreta of man and other animals are the principal original vehicles of infection and contagion, one of the first problems of sanitation is the safe disposal and disinfection of excreta. Various devices for the disposal of the wastes of animal life have had their day, but only two need now be mentioned, viz., the "dry-earth" system and the "water-carriage," or "sewerage," system. The former was at one time in high repute, and in some cases, as in farm-houses, country-houses, and villages, is still useful, especially if water is scarce or difficult to get. It is open, however, to the grave sanitary objection that although dry earth deodorizes well, it does not necessarily disinfect; while on the practical side the system is much less convenient than disposal by water-carriage. The introduction of running water for other purposes, even into farm-houses and villages, has also greatly favored disposal

by sewerage; so that the windmill and the cesspool have made unnecessary almost anywhere either the earth-closet or the privy.[1] In view of the now limited use of the dry-earth system we need not dwell upon it further.

In the water-carriage (or sewerage) system, which is now so generally adopted and so familiar as to require no description the vehicle of infection is *sewage.* This substance is of special and fundamental importance in sanitary science, first, because of its character as a common carrier of excreta and a vehicle of infection; second, because of its ubiquity and abundance in modern life; and third, because it may contain not only the bowel discharges and urine of the diseased, but also the excreta from the mouth and the skin. In brief, sewage may be made up of all the original vehicles of disease, — the excreta from the skin; from the alimentary and pulmonary, and from the genito-urinary tracts; and it is also subject to indirect infection from infected earth, air and water serving as secondary vehicles.

The cleansing and disinfection of sewage is commonly described as its "purification," but before proceeding to consider this problem, one of the most pressing and one of the most difficult of the sanitary arts, we must inquire somewhat more closely concerning the nature of sewage, its origin and its fate.

§ 2. — *Sewage: its Genesis and Composition*

The word "sewage"[2] signifies "drainage" and may be defined as the contents of drains; but it must be distinctly

[1] For an elaborate defence of the sanitary efficiency of the Dry-earth System, see Buchanan, Twelfth Ann. Rep. Med. Off. Privy Council, 1869. *Per contra,* see Sinnhuber, Inaug. Diss. Königsberg, under Esmarch. Baumgarten's *Jahresbericht,* XII (1896), 844.

[2] In common parlance the terms "sewage" and "sewerage" are often confounded. It is usual, however, as it is certainly preferable, to reserve the latter for the *system of sewers,* and to use always the word "sewage" for the *liquid contents of sewers.*

understood that the drains in this case shall be house drains and shall contain domestic drainage. The under-drains of a wet piece of uninhabited land, for example, contain drainage but no sewage, the idea of sewage being connected exclusively with the drainage of houses and human beings, or at least with the wastes of animal life. Sewage is composed ordinarily of the washings of sinks, the emptyings of water-closets, the discharges from laundries, bakeshops, stables and similar places, together with the rain water from roofs and the washings of streets. It may also contain the refuse from slaughter-houses, pus and other substances from hospitals, the washings of markets — in fact, almost anything capable of carriage by water, and small enough to find entrance into sewers. The excreta of human beings, washings from the skin, sputum, bowel discharges, urine, — in short, all excreta excepting the breath, — may be present in sewage.

Nevertheless, ordinary American sewage, on account of its vast dilution, is much less objectionable to look at than is commonly supposed and it often merely suggests in appearance dish-water or dilute milky liquids with some dirt in suspension. The average composition of the fresh domestic sewage of an American city (Lawrence, Mass.) for 1897 was, during the morning, when the sewage was relatively strong, as follows (parts per 100,000): —

Free Ammonia	Albuminoid Ammonia			Chlorine	Nitrogen as —		Oxygen Consumed	Bacteria per Cubic Centimetre
	Total	Soluble	Insoluble		Nitrates	Nitrites		
3.19	1.26	.78	.48	13.36	.18	.0182	7.59	4,726,000

The sewage of European towns is usually much more concentrated than that of American cities, and is there-

fore darker in color, less watery or milky and more objectionable in appearance.

§ 3. — *The Dangerous Elements and Properties of Sewage*

These consist chiefly in the disease-producing organisms which may be present. There is every reason to suppose that sewage free from such organisms might be swallowed without serious harm, and would be rather in the nature of a poor than a dangerous material. Inasmuch, however, as sewage contains or may contain the excreta of human beings or other animals, and inasmuch, further, as has been shown above, as it is by way of these excreta that infection travels, sewage must always be regarded as dangerous, either to come into contact with, or to admit into the body through wounds, or in or upon food materials. There is reason to believe that the only really dangerous properties of sewage reside in the infectious elements referred to. The ordinary decomposition of sewage may indeed lead to the generation of objectionable gases, which shall temporarily prejudice or damage the organism. But there is every reason to believe that the dangers of sewer gas have been much exaggerated, and that many cases of disease have been charged to sewer gas which were really due to the invasion of micro-organisms from other and very different sources. To the consideration of this question however, we shall return hereafter (Appendix, p. 347).

§ 4. — *Importance of the Sanitary Disposal of Sewage*

Inasmuch as sewage may at any time contain any or all of the excretions of the animal body, and inasmuch further as these may contain actively infectious materials, the safe and proper disposal of sewage is one of the first necessities of sanitary science and the public health. Among primitive and uncivilized peoples no special pains are taken for the disposal of sewage or the excreta of animals, but

in civilized societies various and costly devices are employed to this end. The most primitive method is that in which the wastes of life are simply deposited or thrown out upon the surface of the earth in the neighborhood of human habitations, and when the latter are widely separated little or no harm may result from this practice. When, for example, in country districts or elsewhere, the untidy housewife disposes of dish-water by simply throwing it from a window, no particular harm may result if the quantity thus disposed of is not too great, and the dousing of the soil below is not too frequent, especially if the soil be open, porous or sandy. We shall shortly see that in this case, and in the similar cases in which manure is applied to land in large quantities and in successive years, the organic wastes present are speedily mineralized or converted into inorganic matters, by the agency of bacteria residing in the soil in such overwhelming numbers as to form a density of population almost inconceivable, and entitling us to describe the surface layers of the earth as "the living earth."

§ 5.—*Disposal of Sewage in Rivers*

Whenever a city or town introduces a system of sewers, it is easy and natural in many cases to dispose of the sewage by simply letting it run from the principal sewer or sewers into a neighboring brook or river or other stream. It is easy, because the natural drainage is in the direction of the river, which is often little more than the principal natural drain of the neighborhood. It is natural, because the river being, as stated, the ordinary drain of the neighborhood, carries off not only the water which falls upon its watershed but also anything that will float upon or mingle with the water; and in most cases even before it is proposed to introduce sewers, the stream has long been used as an easy means of ridding the neighborhood of

rubbish or wastes of various descriptions. It cannot be denied that, in case the amount of sewage to be got rid of is relatively small, and provided the stream is nowhere below used as a source of water supply, this practice may not necessarily be objectionable; but even in such cases it is generally unwise, because under slightly different conditions, such as growth of the population upon the watershed, or unexpected drought, the presence of a relatively large amount of sewage may produce a nuisance, and prejudice the public health, finally transforming the stream from something capable of giving pleasure, into an open sewer shunned by all mankind.

How, then, it will naturally be asked, has it happened that so many important cities and towns all over the world freely dispose of their sewage by simply turning it into the nearest watercourse? The answer is easy. It is simply because until very lately engineers, chemists and sanitary experts, alike held as true a theory of the purification of watercourses which is now known to be false, or, at best, only a half truth. This was the famous theory of the "self-purification of streams," to a brief consideration of which we may now turn.

§ 6. — *Theory of the Self-purification of Streams*

This theory was based upon the obvious fact that although a very large amount of sewage might be suddenly poured into a stream at a given point, so that at that point the pollution was conspicuous and self-evident, it was only necessary to follow the stream for a short distance to perceive that the water had distinctly improved in appearance. This result of mere inspection was strongly confirmed by the chemistry of the time, which proved by actual analysis that the organic matter in the water, and the results of decomposition, were decidedly less at the lower than the upper point. Naturally, only one conclusion could be

drawn from the premises. The stream had somehow purified itself while flowing, and the corollary was deduced that "running water purifies itself." (*Cf.* p. 231.)

The importance and far-reaching effects of this conclusion can hardly be overestimated. Relying upon it, numerous cities and towns all over the world introduced water supplies derived from sewage-polluted streams, and infinite damage was done to the public health. The theory is now abandoned, or rather accepted only after so much modification that it is virtually new. There is, indeed, a considerable purification effected by streams, but it is mostly purification by dilution; and, as we shall see in a later paragraph, distrust of this theory has produced profound changes in our points of view. The disposal of sewage in rivers is always to be deprecated unless the volume of sewage discharged is very small in proportion to the dry weather flowage of the stream in question. It is not to be tolerated if the river below is, at any point, however remote, used without purification as a source of water supply; and it is often not desirable even with such purification.

§ 7. — *Sewage Disposal in Lakes*

Some cities are so situated that it is convenient and natural for them to drain into bodies of fresh water, either lakes or ponds, in which there is little or no current such as always exists in a river. In these cases, the success of the practice, so far as the mere disposal of sewage goes, depends chiefly upon the proportion maintained between the volume of sewage and the volume of the water into which it is discharged. This will be seen most clearly by simply considering the extremes, in which cases, for example, a large city empties its sewage into a small pond; or, on the other hand, a small town pours its sewage into a large lake. In the former case, the results would be disastrous, the pond being very soon converted into a sew-

age pool. In the latter, no perceptible effect would be produced. Obviously, there must be a large class of cases, comprising cities and towns of moderate size located upon relatively large bodies of quiet water, which may drain with safety into lakes or ponds; but it is equally clear that there is also another class of cases, comprising for the most part large cities, situated upon relatively small bodies of quiet water, which cannot drain into these without seriously prejudicing their purity and possibly producing a nuisance.

Furthermore, the case is complicated seriously if either a city or a town draining into a lake or pond undertakes to derive its water supply from the same lake, or if any other city or town, no matter how remote, makes such use of the water. This aspect of the problem, however, need not detain us at this point but may be reserved for the consideration which it requires until a later chapter. It is enough in this connection to note that very many of the cities and towns of the United States do as a matter of fact dispose of their sewage by emptying it into lakes or ponds, and that, too, with entire success so far as the mere disposal of the sewage alone is concerned. Examples are the cities and towns bordering the Great Lakes, and in the list are some cities of large size such as Chicago, Milwaukee, Duluth, Cleveland and Toronto.

§ 8.—*Disposal in Harbors, Estuaries and the Sea*

Another class of cities and towns, and this includes some of the largest in the world, are so situated that their natural drainage is either directly into the sea, or into some tidal harbor or estuary. In these cases it is easy and natural to dispose of sewage by simply pouring it into the sea, harbor, or estuary at some convenient point or points; and here, also, as in the preceding case, if the city or town is not too large in proportion to the volume of water at its doors, no harm comes from such disposal. There is, in this case,

the obvious advantage that such bodies of water are never used as sources of water supply, so that one serious element of difficulty which exists in the case of lakes and other bodies of fresh water may here be neglected. As a matter of fact, numerous cities and towns on our own coasts pour their sewage into salt or brackish waters, often with entire success and with the absence of all complaint. It is only, indeed, in very rare cases, that this system of disposal causes trouble, and in these instances the cities are usually situated not directly on the sea itself, but upon some narrow arm of the sea or some tidal river which virtually limits the size of the body of water into which the sewage is poured. Such a case is that of London, which is situated not upon the sea, but upon a tidal river, and even in the case of London the sources of complaint have been based more upon the alleged obstruction to navigation caused by deposits in the shallow river than upon sanitary grounds. No such complaints, at least of a serious character, have as yet arisen in the case of cities like New York, Philadelphia or Boston, or indeed, so far as the writer is aware, in any instance excepting that of London; so that we may probably conclude that disposal in the sea or in its harbors or estuaries may safely be regarded as one of the most satisfactory methods of sewage disposal hitherto discovered or employed.

§ 9.—*Principles involved in the Disposal of Sewage in Rivers, Lakes, Estuaries and the Sea*

In all these cases the fundamental principle of purification, and the basis of successful disposal, is simple dilution, by a relatively large volume of purer water. Other factors may or may not coöperate as, for example, in the case of a swiftly flowing river. The mere fact of removal sometimes constitutes an important contribution to successful sewage disposal, the sewage being speedily carried away

to a point where its existence is of little consequence, as for example, may happen in an estuary or tidal river, the mere movement of the water constituting an efficient method of transportation of the sewage from a point where it would be objectionable to a point where its presence is unobjectionable. But this is not all. Dilution is the fundamental phenomenon, and lies at the bottom of much of the purification which, undoubtedly, takes place in all these cases. Mere removal does not, in itself, contribute to purification, while dilution certainly does do so. There are, however, other forces at work which contribute materially to purification by dilution, and these are best seen and studied in the case of the discharge of sewage into the relatively quiet waters of a lake, where they are not complicated or masked by currents, or by the flowing of a stream. Such instances are common and easily studied, and, as an example, we may take the case presented by the sewage disposal of Burlington, Vt. (*Cf.* p. 234.)

Burlington is a city of fifteen thousand inhabitants, situated on Burlington Bay, a broad easterly expansion of Lake Champlain. The sewage of the city is collected into one large outfall sewer which empties near the southern extremity of the city directly upon the lake front into the waters of the lake. At this point Lake Champlain is so broad that the only currents perceptible are those produced by winds, and, accordingly, these move sometimes in one direction, sometimes in another, but as a rule are confined to the surface, so that, on the whole, there is very little motion of the lake water in any particular direction. The author has made repeated examinations of the sewage in the outfall sewer and of the mixed water and sewage at various points within one mile of the sewer outlet, and the results show that while the crude sewage is not materially different from that observed in most American cities, and contains in round numbers about one million of bacteria

per cubic centimetre, the lake water even one hundred feet away shows already only perhaps a thousand, which number rapidly declines as we recede from the sewer, until at a distance of a half mile and more it begins to be difficult to find any evidence of the presence of sewage, either by chemical or by bacteriological analyses.

A little reflection will show that the mere dilution of the relatively small amount of sewage by the relatively enormous volume of the lake would alone account for most, if not all, of the facts in the case. But there is good reason to believe that other factors of purification exist and have their influence. In the first place, many of the sewage bacteria, and probably all of the most dangerous, are by preference thermophilous, or, so to speak, warm-blooded, having recently come from the bodies of warm-blooded animals in which they have existed and perhaps thriven. These, therefore, find the temperature of sewage hardly favorable to their continued existence or development, and when plunged into the still colder waters of the lake are subjected to conditions far less favorable. In the next place, in the bodies of their hosts these bacteria have found not only a favorable temperature, but also rich supplies of food. Once they begin to travel through soil pipes and sewers, their food becomes scarcer and less available, and when finally they mingle with the waters of the lake, which are relatively pure and destitute of organic matters, their pabulum must be distinctly scanty. At the same time, in sewage and in the lake, they are subject to the influence of gravity which tends to draw them down into the deeper, quieter layers and finally into the mud at the bottom, while predatory infusoria ranging through the water may devour them altogether. Lastly, if they tend to float or linger on the surface, they may there suffer from the germicidal action of the rays of light and perish.

All of these unfavorable influences which accompany the ordinary process of dilution in lakes, rivers, estuaries

and the sea may be either hindered or exaggerated by movement of the water, such as occurs in a flowing stream, or in tides and other currents, and they, and all other conditions tending to the inhibition of the growth, or to the destruction altogether, of microbic life, may all be summed up in one phrase, namely, "unfavorable environment." There is reason to believe that the purification of sewage by dilution, in respect at least to its living, organic contents, is, as a matter of fact, considerable, though often incomplete, and that the forces enumerated and which we have described collectively as "unfavorable environment" play the principal part in whatever purification actually takes place. Inasmuch, however, as many micro-organisms are capable of successfully resisting for a long time the effects of an unfavorable environment, bacteria being in some cases especially resistant, it is easy to understand that the purification of sewage by dilution, even when accompanied by the factors mentioned, is often incomplete and never to be relied upon, except in the presence of satisfactory evidence. In the case of sewage disposal in salt water this is a refinement of small consequence, but in the case of fresh waters, such as lakes and rivers, which it may be desirable to use for public water supplies at points more or less remote from the place of disposal, the question assumes the highest possible importance, and to this aspect of the subject we shall return in Chapter IX.

§ 10. — *Purification of Sewage by the Living Earth*

Reference has already been made above, in § 4, in some detail to the primitive method of sewage disposal in which the wastes of life are got rid of by simply throwing them upon the earth. In this case, and in the similar case in which manure is applied to land in large quantities and for many successive years, the organic wastes present are speedily mineralized, or converted into

inorganic matters by the agency of micro-organisms (bacteria) which reside in the surface layers of the earth in astonishing numbers.

The commonly received idea of the earth, that it is typically inorganic and lifeless, has been shown by modern researches to be singularly incorrect. Every one is aware that various living things, such as woodchucks, moles, snakes, and even certain birds, as well as numerous insects and innumerable plants, spend a part or the whole of their existence in the earth. And yet, when, in 1881, Darwin drew general attention to the enormous number of earthworms living in the upper layers of the earth, his treatise occasioned widespread surprise. All these forms of life, however, are as nothing in comparison with the myriads of bacteria which have their home in the earth. A single grain of garden soil, for example, may contain as many as a hundred thousand of these microscopic organisms, and there is reason to believe that the soft, clammy feel of moist loam is in no small measure due to the presence of bacterial bodies. In many cases the inorganic grains which loam contains are mantled, as it were, by a jelly-like substance, probably produced by these organisms, and in which their bodies are embedded. It is no exaggeration, therefore, at present, to speak of the surface layers of the earth, especially in fertile regions, as if they were alive, or of the upper layers of the earth itself as constituting a "living" rather than a lifeless earth.

If now we consider what may take place when the organic wastes of life are thrown upon this porous, living earth, we may perhaps understand the remarkable process of purification which takes place. When, for example, the farmer periodically dresses his fields with manure consisting largely of the wastes of animal life, we need not be surprised if, after a time, these wastes seem to have disappeared, while the soil upon which they were placed has grown correspondingly soft and rich. Precisely as, under

similar circumstances, the earthworms which are present appear to flourish and multiply under the favorable conditions provided for them by the farmer, so, we have reason to believe, the infinitely smaller micro-organisms — which, like the earthworms, reside in the upper layers of the earth, — feed, flourish and multiply upon the food thus provided for them; and exactly as the earthworms work over the materials upon which they feed, reducing them in chemical complexity, and turning organic into inorganic matters, so the myriads of micro-organisms which surround them on every hand do their appointed work, and mineralize the organic wastes upon which they too feed and fatten.

If what has just been said is true, it is easy to understand how it is that even repeated applications of large amounts of organic matters, such as stable manure, may be successfully made to a given area of land; or how it happens that the untidy housewife may, with comparative impunity and for a long period, habitually throw from the window upon a limited piece of earth the organic wastes of the kitchen; or, finally, the fact that some of the largest cities in the world, such as Berlin, successfully dispose of all their sewage by simply pouring it upon the land. There is every reason to believe that this method of sewage disposal, which is successfully in operation under either natural or artificial conditions all over the world, is, at the same time, one of the most primitive, one of the most practical, and one of the most perfect, systems hitherto employed by man. We may, therefore, in the next paragraphs, properly devote considerable attention to its theory and practice. By a curiously unfortunate use of words this process has come to be known by the altogether inadequate term "intermittent filtration." As we shall now see, intermittent filtration lies at the basis of all sewage disposal by irrigation and of all successful sewage-farming.

§ 11.—*Intermittent Filtration*

In all cases of sewage disposal upon land, whether crops be grown upon the land or not, the fundamental processes at work are those involved in intermittent filtration, and this, as has been explained in the preceding paragraph, consists in biological and chemical treatment of, or reaction upon, sewage by the living earth.

It has long been known that earth and soil are remarkably effective in the purification of sewage. Everyday observation, such as that described in the preceding section in connection with the ordinary operations of agriculture, proves that land-disposal of organic wastes is perfectly natural and successful. The process, consisting as it does in a change of organic into inorganic matter, early attracted the attention of chemists, and inasmuch as the purification, chemically speaking, consists largely in oxidation of nitrogenous bodies with conversion of the latter into nitrates, the essential phenomenon is often described as "nitrification."

§ 12.—*English Experiments on Intermittent Filtration*

At first it was supposed that nitrification was due to the direct action of the oxygen of the air upon complex nitrogenous bodies, but it was soon perceived that something more must be at work. It was evident, for instance, that stable manure exposed to an abundance of oxygen in the air remained unaffected, while if it were brought into contact with the soil in the ordinary process of agriculture, it speedily disappeared, giving rise to nitrates in abundance. Laboratory experiments showed further that the nitrification could readily be set up by introducing earth into mixtures which it was desired to nitrify, so that it seemed perfectly clear that somehow the earth possessed a specific, nitrifying power. Some supposed that this was due to its porous character which might produce oxidation somewhat after the fashion of platinum sponge.

The first experiments on the disposal of sewage upon land or earth were laboratory experiments made by the Rivers Pollution Commissioners of Great Britain appointed in 1868, in connection with their investigations of the pollution of rivers, and were most instructive. In these experiments, glass tubes, sixteen feet long and two inches in diameter, and glass cylinders, six feet long, and either ten and one-fourth or twelve inches in diameter, were filled with various kinds of soil. Each then received at the top (or in some cases at the bottom) known amounts of sewage which were discharged as effluent at the other end, and in the case of downward intermittent filtration were found to have been remarkably purified. A full report of these important investigations may be found in the First Report of the Rivers Pollution Commission appointed in 1868, published in 1870. (Mersey and Ribble Basins, Vol. I, pp. 60–70.) The facts developed by these experiments remained, however, largely unexplained until a few years later when the investigations of other observers drew attention to the probable coöperation of micro-organisms in the processes of nitrification. Moreover, the Commission's experiments were conducted on a laboratory scale, and were limited in number as well as in time.

§ 13. — *The Problem Attacked in Massachusetts*

It remained for the State Board of Health of Massachusetts to take up the problem where the Commission had left it, and to make for the first time extensive and elaborate experiments upon a large scale with the aid of bacteriology as well as chemistry, upon the purification of sewage by land treatment or "intermittent filtration." Inasmuch as these investigations were the first to be made on a large scale and for a long time, and inasmuch as they have now become classical, we may describe

them, together with the conditions which led up to them, in some detail.[1]

The state of Massachusetts, especially in its eastern portion, had become, by 1880, so thickly settled that the disposal of the sewage of the numerous cities and towns composing the metropolitan district having Boston as its centre was becoming a serious problem. Accordingly, in 1881, a Commission was appointed to consider and report upon the drainage of the Mystic and Charles River valleys. The report of these commissioners recommended a metropolitan district system which should preserve as far as practicable by general sewerage the purity of the water supplies of the cities included in this district. In 1884 the Massachusetts Drainage Commission was appointed, and in 1886 their report was published, giving a large amount of valuable information regarding sewage disposal theories and practices in England and on the Continent. Perhaps the most important work which they accomplished, however, was their earnest recommendation that the commonwealth of Massachusetts should appoint a Commission or designate Guardians to conserve the purity of the inland waters of the state, such body to be provided with advisory rather than mandatory powers.

"Let these guardians of inland waters be charged to acquaint themselves with the actual condition of all waters within the state as respects their pollution or purity, and to inform themselves particularly as to the relation which that condition bears to the health and well-being of any part of the people of the commonwealth. Let them do away, as far as possible, with all remediable pollution, and use every means in their power to prevent further vitiation. Let them make it their business to advise and assist cities or towns desiring a supply of water or a system of sewerage. They shall put themselves at the disposal of manufacturers and others using rivers, streams, or ponds, or in any way mis-

[1] For an interesting and valuable historical statement of the rise and treatment of the drainage problem in a growing community, see Report of a Commission appointed to consider a General System of Drainage for the Valleys of Mystic, Blackstone, and Charles Rivers. Boston, 1886.

using them, to suggest the best means of minimizing the amount of dirt in their effluent, and to experiment upon methods of reducing or avoiding pollution. They shall warn the persistent violator of all reasonable regulation in the management of water, of the consequences of his acts. In a word, it shall be their especial function to guard the public interest and the public health in its relation with water, whether pure or defiled, with the ultimate hope, which must never be abandoned, that sooner or later ways may be found to redeem and preserve all the waters of the State. We propose to clothe the board with no other power than the power to examine, advise, and report, except in cases of violation of the statutes. Such cases, if persisted in after the notice, are to be referred to the attorney general for action. Other than this, its decisions must look for their sanction to their own intrinsic sense and soundness. Its last protest against wilful and obstinate defilement will be to the General Court. To that tribunal it shall report all the facts, leaving to its supreme discretion the final disposition of such offenders."[1]

§ 14. — *Reorganization of the State Board of Health of Massachusetts*

The legislature of 1886 promptly adopted the recommendation of the Drainage Commission, and turned to the State Board of Health as the proper body to undertake the new and important functions which it was proposed to create. The Board was reconstituted and reorganized, and endowed not only with the usual powers and duties of a State Board of Health, but with entirely new and peculiar functions in regard to the water supplies and sewerage of the towns and cities of the commonwealth. The board was to become the expert sanitary adviser of the towns, and *a fortiori* of the legislature, in these particulars; and it was to be liberally supported. As a special recognition of the new functions, Mr. Hiram F. Mills, of Lawrence, perhaps the most distinguished hydraulic engineer within the state, was made a member of the reorganized Board, and immediately took charge of the experiments upon intermittent filtration.

[1] Massachusetts Drainage Commission Report (full reference given above), p. lxi. Boston, 1886.

The statute which provided the new functions for the Board was approved on June 9, 1886, and was entitled "An Act to protect the Purity of Inland Waters." In substance, and to a large extent in form, it corresponds with one recommended by the Drainage Commission. It has proved to be one of the most novel and satisfactory enactments for the benefit of the public health ever undertaken in America. In one important respect the statute actually adopted differed from that recommended, namely, in providing that the members of the Board should serve without pay. The special functions of the State Board of Health as laid down in this statue, concisely stated, were as follows: —

1. To have the general care and oversight of all the inland waters of the commonwealth.

2. To recommend legislation and suitable plans for systems of main sewers for the state.

3. To cause examinations of the waters of ponds and streams to be made.

4. To recommend measures to prevent the pollution of waters.

5. To conduct experiments on the purification of drainage.

6. To conduct experiments on the disposal of manufacturing refuse.

7. To consult with and advise the authorities of cities and towns, or with others, with reference to water supply and drainage.

8. To consult with and advise manufacturers with reference to the disposal of manufacturing refuse.

9. To bring to the notice of the attorney general all omissions to comply with existing laws.

The act further provides that authorities of cities and towns, and all others intending to introduce systems of water supply or sewerage, shall submit to the Board outlines of their proposed plans or schemes in relation to

these subjects; and that manufacturers intending to engage in any business, drainage or refuse from which may tend to cause the pollution of any inland waters, shall also give notice to the Board of their intentions. The Board immediately proceeded to carry out the provisions of the act, and in its first report, dated January, 1887, it states *in extenso* precisely what it proposes to do if adequately supported, and concludes: —

"In order to make the series of examinations above outlined, including monthly analyses of all waters used for domestic supply in the state, and biological examinations of certain waters injuriously affected by animal life, together with chemical analyses of other inland waters; to conduct contemplated experiments upon the purification of sewage and refuse from industrial establishments; to make the necessary investigations in order to advise cities, towns, corporations and individuals in regard to the best method of disposing of their sewage; and to carry out the other provisions of Chapter 274, — the board estimates that the sum of $30,000 [for the first year] will be required."

§ 15. — *The Lawrence Experiment Station of the State Board of Health of Massachusetts.*

The commonwealth cheerfully did its part, the legislature granting the large sum asked for by the Board which thereupon proceeded to complete its organization for work along the lines indicated. It announced that it was ready to consult with and give advice to any Massachusetts city or town concerning its water supply or sewerage. At the same time it was distinctly held by the Board that, in order to give adequate and really expert advice, it must experiment and investigate. It was not to rest content with the scanty or imperfect knowledge of these subjects which was too often all that was available, or to accept without trial the methods or the results of scattered or local observers;

but, first, to investigate for itself the actual condition of the various water supplies of the state by all means in its power, whether engineering, chemical or biological; and, second, after having obtained all available information at home and abroad, to establish an experiment station, and make for itself investigations upon the long vexed questions of the purification of sewage and drinking water.

This station, the Lawrence Experiment Station, the first of the kind in America, if not in the world, was located in a building adapted for the purpose, which had been constructed upon land on the left bank of the Merrimac River, belonging to the Essex Company and already used at an earlier date by Mr. Mills for experiments in hydraulics.

§ 16. — *The Massachusetts Experiments at Lawrence*

The first problem attacked at the Lawrence Experiment Station was that of the best method for the disposal of sewage upon land. English and German experience had made it probable that much might be done in this direction in America; but the knowledge available was very limited and of little or no practical value to American engineers, because the climates, soils, sewages, and civil and economic conditions of America are so different from those of Europe. Accordingly, in November, 1887, a series of careful experiments was begun, to test the purifying capacity of various soils and sands occurring in Massachusetts.

For this purpose, a number of large wooden tubs or tanks built of cypress were cautiously filled with different soils, ranging from muck and garden loam on the one hand, through fine sand and coarse sand to mixed gravel stones, coarser materials, and pebbles on the other. The soil or sand to be tested was in each case supported by a stratum of stones and gravel, and underdrained through an effluent pipe which emptied into a large measuring basin. The sewage was also measured as it flowed on at the top, and

the whole experiment was under control in every respect. Each tank, or "filter," was sixteen feet in diameter, or one two-hundredth of an acre in area, and the filtering material in each case was five feet in depth. The sewage to be experimented with was drawn from one of the main sewers of the city of Lawrence, and was ordinary domestic city sewage, free from manufacturing wastes. No experiments of this kind had ever before been undertaken on such a scale or with so much care. For the first time in the history of science, engineers, chemists and biologists worked together under the direction of a master in hydraulics, toward one common end, — the promotion of the public health.

The results crowned the endeavor. Intelligent by-standers, who saw the sewage flowing upon the filters, at the outset unhesitatingly predicted failure. They felt certain, and did not hesitate to express their belief, that in a fortnight, at the latest, the filters would become clogged and foul, and the whole neighborhood pestilential. They did not know that Berlin, the German capital, disposes of all its sewage upon land. They forgot that the farmer once a year, or oftener, manures his fields with filth, and that the hungry earth receives the gift with open mouth, devours it, and soon cries out for more. As soon as a few days had passed, and the filters had become established, the effluent began to grow bright and clear. Chemical analyses showed that the out-put was now purified sewage, comparatively free from odor, and poor in organic matters. Bacterial analyses showed that while earlier, as sewage, it was swarming with the germs of putrefaction and decay, it now contained only a few bacteria. Further studies revealed the fact that the foulness of the sewage was not held back as by a strainer; but rather that as wood by a slow fire is turned to ashes, the organic matters here were slowly reduced to mineral substances. No disagreeable odor developed, and the filters showed no signs of clogging. Thus the very name

"filter" became a misnomer. The by-standers were amazed, and could not repress their feelings of surprise and admiration.

§ 17.—*Anatomy and Physiology of Intermittent Filters*

Meanwhile the data of the experiments were accumulating. Winter came on, and still the "filters" did their work. Already it was proved that land-disposal of sewage was possible for America. But, curiously enough, those soils—such as muck and garden loam—which many had predicted would be the most useful, proved to be the least effective. They were too close in texture, too fine, too impervious; while sand (such as ordinary mortar sand) or even fine gravel proved to be the most effective. And, on looking into the reason why, it was soon perceived that the whole process is a vital one. The soils are not mere strainers, for at the very outset they fail to work. They are rather like the living sponge,—an animal whose body is everywhere channelled with fine passages lined with living cells. The fine passages in the body of the filters are the spaces between the sand grains; the living cells are the micro-organisms which, after a few days, come to dwell upon the sand grains and line the passages. And very much as the living cells of a sponge detain and destroy the organic particles passing by them, the bacteria resident upon the sand grains detain and work over the organic matters of the sewage poured upon the filter. Again, exactly as the living organisms of which a sponge is essentially composed require oxygen to support their respiration, so those inhabiting a filter must have abundant air. This means that the sewage, which is usually destitute of oxygen, must not be applied continuously, but *intermittently*, so that air may follow it down through the filter and keep from suffocation the purifying micro-organisms. And this also explains why intermittent downward filtration, under the right con-

ditions, is always successful, while continuous filtration, or upward intermittent filtration, of sewage inevitably fails.

With the main principles once established, it remained only to learn the details of their application. Sand proved better than loam, because it allowed better ventilation. Fine sand proved better than coarse sand, because it seems to be the happy mean, giving full exposure to the air by distributing the sewage in thin films over a vast number of surfaces, but yet allowing sufficient ventilation.

The practical results were quick to follow. Once the purifying values of sands of particular sizes were established, it remained only to obtain samples of sand from any town desiring to dispose of its sewage on land, and to examine and compare them with known sands, to be able to predict for that community either success or failure. The town of Framingham soon constructed a large municipal filter under the advice of the Board, and it has proved an unqualified success. The city of Brockton soon after followed suit, and built an admirable system of intermittent sand filters for the disposal of its sewage. Henceforward any city or town — not only in Massachusetts, but in America, or in the world — may, if its soil be right, and other conditions favorable, adopt, with perfect confidence, systems for the land-disposal of sewage.

§ 18. — *Theoretical Aspects of Intermittent Filtration*

Enough has now been said to make it clear that intermittent filtration is not really filtration at all, in the etymological sense, but rather a biological and chemical process of extreme delicacy. A field of sandy soil may, it is true, be a very effective strainer; but if worked intermittently, it is much more than this. A mere strainer soon chokes, and must be cleaned; but an intermittent filter does not readily choke, and is largely self-cleaning. This is a phenomenon which can be actually witnessed. When sewage

began to be applied to the several tanks outside the Lawrence Experiment Station, even the most intelligent of the workmen predicted that the filters would soon choke and become a nuisance; but after two years of actual operation, hardly anything more remarkable or objectionable could be seen upon them than upon other fertile land. This simple ocular demonstration was confirmed by the results of analysis, and the mechanical theory is readily disproved by a comparison of the chemical composition of the effluent with that of the affluent. In the life-history of an intermittent filter there is usually a period at the outset when there is but little, if anything, more than a mechanical purification; but under the best conditions there speedily begins a change of the profoundest significance. The dissolved organic matters no longer pass out as they came in; the suspended matters for the most part cease to accumulate; and both appear in the effluent under other forms. Obviously, mechanical processes alone could not effect such changes; and besides, these changes may occur under conditions which exclude entirely the purely mechanical hypothesis. A most striking example of this kind is to be found in the operation of a tank composed of small stones, the spaces between which are, as compared with much of the organic matter of sewage, of infinitely large size; yet the changes wrought by this filter are far more extensive, and the purification is far more complete, than in filters of peat or garden soil, which are mechanically nearly perfect strainers. It would be hard to find a better example of the possibilities of sewage filtration than such a tank supplies; yet this filter testifies in the clearest manner to the absolute insignificance of any merely mechanical factor in the purification of sewage by intermittent filtration.

§ 19.—*Intermittent Filtration a Biological Process*

A theory much more reasonable than the mechanical hypothesis is that the action of an intermittent filter is

fundamentally chemical. Of the powers of intermittent filters to effect chemical changes there is no question, as the previous pages of this chapter abundantly testify. Moreover, the transformations effected are so thorough that the analogy of purification by fire must occur to every thoughtful observer. Very early, however, the existence of an additional factor began to be recognized. Thus the Rivers Pollution Commission in their experiments on intermittent filtration, although insisting upon the chemical character of the purification obtained, referred to the process as an act of respiration, adding, most unconsciously, the vital to the purely chemical idea: "From all of these experiments, then, it appears that the action of the filter must not be considered as merely mechanical. The process carried on in it is also chemical. . . . A field of porous soil irrigated intermittently, virtually performs an act of respiration." (Cf. p. 150.)

It has since been definitely established, moreover, that micro-organisms are an indispensable element in the constitution of a successful intermittent filter, so that the essentially chemical theory has given place to one essentially vital, or biological.

"Upon the biological theory, an intermittent filter is no longer regarded as a mechanical strainer, nor is it merely a chemical furnace; it resembles a living organism." [1]

§ 20. — *Objections to Intermittent Filtration*

The Rivers Pollution Commissioners' *a priori* criticisms of the practical value of intermittent filtration are worthy of note as we bring this section to a close: —

"Nevertheless there are three formidable objections to the general adoption of this process: first, it is entirely unremunerative, the amount of sewage applied to a given acre of land being probably in such a case

[1] Experimental Investigations by the State Board of Health of Massachusetts upon the Purification of Sewage by Filtration, etc. p. 861. Boston, 1890.

too great to permit of the growth of any ordinary agricultural crop; second, the whole of the manure ingredients of the sewage would be absolutely wasted; and third, the collection of solid fæcal matters upon the surface of the soil, with no vegetation to make use of them, would probably give rise to a formidable nuisance, especially in hot weather. We also entertain doubts as to the process being equally successful under ordinary management on a large scale, since the sewage would be likely to pass through the land in an unequal manner — in some places reaching the drains very rapidly, in others passing through the soil too slowly. . . . Filtration, properly conducted, results in the oxidation, and transformation of offensive organic substances in solution, as well as in the mere mechanical separation of the suspended solid matters which, when in motion, sewage conveys with it. If the process could be carried one step farther, and those harmless inorganic salts, which are carried off by the effluent water of a perfect sewage filter in too dilute a solution to be profitably extracted, could be converted into something positively useful, the remedy would be complete. We should have succeeded in not only abating an injurious nuisance, but in realizing a product which would help to refund expenses. This further step is possible in the great majority of cases; and it is to the plan of using sewage in irrigation, as being in reality a filtration of the best kind, plus a conversion of its filthy contents into valuable products, that we have now to direct attention." — *Rivers Pollution Commission of 1868, Report*, Part I, p. 70. London, 1870.

The objections here raised that the process is unremunerative and that the end products are wasted, still hold; but the fear that a nuisance must result from the accumulation of matters on the surface of fields devoted to intermittent filtration, has been shown by experience to be groundless. We may now follow the line of thought laid down by the commissioners, and pass on to a consideration of sewage disposal by irrigation.

§ 21. — *Disposal and Purification of Sewage by Irrigation*

In the second report of the Commissioners appointed in 1868 to inquire into the best means of preventing the pollution of rivers ("Mersey and Ribble Basins"), p. 19, sewage irrigation is referred to as a process —

"where sewage has been submitted, by means of irrigation, to the action of a vast mass of soil whose surface is covered with growing plants, which it feeds, whose depth is penetrated by their hungry roots, and whose whole substance provides an immense quantity of material efficient for sewage defæcation. . . .

"If we except the laboratory experiments in the treatment of sewage in the intermittent downward filtration described in our first report . . . no other method of sewage defæcation approaches irrigation in the uniform excellence of its results. It is no doubt very desirable, in the interest of those towns where sewage cannot be dealt with by irrigation, that an experiment in intermittent downward filtration should be conducted on what may be considered a working scale, — when all those difficulties would arise which do not show themselves in a laboratory experiment, and when it would be proved whether the process can be conducted on the drainage water of, say, 20,000 people with the efficiency to which our laboratory experiments pointed, and without creating a nuisance. But the best result under that system would simply be the conversion of a polluting into a non-polluting stream. The injury done by town sewage would in that case disappear, but the agricultural value of it would be wholly lost. By using it in irrigation, on the other hand, the nuisance vanishes, while the fertilizing influence is retained and utilized."

In the first report of the Commissioners, to which reference has already been made in the preceding section, the purification of sewage by irrigation is well described as follows (Vol. I, p. 70): —

"We have still to discuss what may be called the agricultural remedy for the nuisance created by town sewage. In the first place, irrigation involves filtration. . . . But a filter, as has been already shown, is not a mere mechanical contrivance. It is a machine for oxidizing, and thus altogether transforming as well as for merely separating the filth of dirty water. And in this respect especially, irrigation necessarily includes filtration. Sewage traversing the soil undergoes a process to some extent analogous to that experienced by blood passing through the lungs in the act of breathing. A field of porous soil irrigated intermittently virtually performs an act of respiration, copying on an enormous scale the lung action of a breathing animal; for it is alternately receiving and expiring air, and thus dealing as an oxidizing agent with the filthy fluid which is trickling through it. And a whole acre of soil three or four feet deep, presenting within it such an enormous lung surface, must be far superior as an oxidizer for dealing with the drainage

of one hundred people, to any filter that could be practically worked for this purpose.

"To this item in the character of both irrigation and filtration as chemical processes, there must be added another cleansing agency also of a chemical kind, in which the former has very greatly the advantage. We refer to the actual appetite for certain dissolved impurities in filthy water, which soil, whether in a tank or covering a field, owes both to general surface attraction and to the chemical affinities which some of its ingredients possess. This appetite is doubtless very limited in its amount, but it is directly proportional to the quantity of material exercising it. The superior capability of this kind which the soil of a field possesses, in comparison with that in a limited filtration tank, depends partly on the immensely greater quantity of cleansing material which an acre drained perhaps four feet deep necessarily brings to bear upon the filthy fluid; but also and especially on the fact that in the former case this appetite is, except in winter time, always kept alive and fresh by the action of plant growth in constantly removing the deposited impurities, and rebuilding them into wholesome organic structures.

"Considered then merely as a mechanical and chemical agency for cleansing the drainage water of our towns, it seems plain that a sufficient extent and depth of porous soil to be used in irrigation, having periodical intervals of rest, during which the soil drains and becomes refilled with air, certainly must be the best possible strainer, oxidizer, and filter of water which, like the sewer water of our towns, contains nauseous organic impurities, both suspended and dissolved. That it is so, analyses of effluent waters have satisfactorily proved, as will be illustrated at length hereafter. Meanwhile we have further to consider the last great advantage of the soil over all other filters, in that it utilizes a considerable proportion of the substances which they only separate, or at best transform.

"This is the second point in our discussion of the agricultural remedy for river pollution, so far as that is due to the influx of town sewage. Sewage filth is 'fertilizing matter,' and therefore valuable as a manure. Every one is familiar with the idea that the fertility of a farm depends very much on the quantity of the live stock kept upon it. It is, in fact, an established maxim in agriculture that, apart from the use of imported and manufactured fertilizers, the maintenance of fertility depends very much upon the live stock which the farmer keeps upon the land, and the quantity of manure which he can thus apply to it. . . . .

"The process of filtration through sand, gravel, chalk, or certain kinds of soil if properly carried out is the most effective means for the purification of sewage to which reference has yet been made; indeed,

irrigation, as now carried out, owes no inconsiderable amount of its success to the contemporaneous effect of the filtration of the sewage through the soil of the irrigated fields; for it is precisely in those cases in which the sewage is absorbed and disappears in porous land, that we have observed, in the effluent water from drains, the most complete purifying effect." —*First Report, Rivers Pollution Commission of 1886*, p. 60.

§ 22. —*Sewage Farms. Objections to Sewage Disposal by Irrigation and Sewage Farming*

The disposal of sewage by means of irrigation naturally involves the establishment of sewage farms, that is, a special kind of farming in which a liquid fertilizer is supplied in abundance, sometimes in superabundance. Enough has already been said in the preceding sections to show the theoretical importance and value of sewage as a fertilizer. It cannot be denied that sewage possesses elements of large fertilizing value, and it should never be forgotten that it may at some time be made a far more powerful aid than it is to-day in increasing the food supply of mankind.

On the other hand, there is good reason to believe that the practical value of sewage as a fertilizer falls far below its theoretical value, owing chiefly to its enormous dilution; and that any combination of farming with sewage disposal is, closely examined, of doubtful economic wisdom, at least at present, in America. It does not by any means follow that, because sewage contains valuable fertilizing elements, it is therefore wise for every city and town having sewage to dispose of to undertake sewage farming. It must be borne in mind that the civilized world appears to have been everywhere, within the last decade, suffering from a period of agricultural depression due, no doubt, in great part, to the vast modern improvements in agricultural machinery, and especially to the wonderful modern facilities for transportation, which allow food to be carried from almost any point of supply or superabundance to points where it is

in demand, with extraordinary speed and cheapness; and probably also to the remarkable advances which have been made in the arts of food-preserving, by means of which the superabundance of one season or place which was formerly wasted by decay may be conserved with success indefinitely, or until needed either there or at some remote point of the earth's surface. It is hardly necessary, therefore, in a period of depression in agriculture, such as has lately fallen upon much of the civilized world, to undertake agricultural operations at a loss, and it is not surprising that objections to sewage farms have already arisen in some quarters from farmers who are obliged to compete with sewage farming. There can be no doubt that a greater area of land is required for successful sewage disposal by sewage farms, than by mere intermittent filtration, and it is of very dubious wisdom, at least in the United States where land in the neighborhood of cities is dear, where municipal servants are likely to be highly paid, and where, also, agricultural produce is cheap, to undertake sewage farming either for economic or æsthetic reasons. Moreover, as has already been suggested, there are other objections than the purely economic. Quite recently it was found somewhat difficult for the city of Paris to secure the privilege of adding to the area of its sewage fields because of the formidable opposition of the ordinary farming interests, which alleged with considerable vehemence that it was difficult for them, unprovided as they were with sewage as a fertilizer, to compete successfully with the sewage farms already in existence, upon which larger crops could be more cheaply produced.

There is also the sanitary objection, the force of which must to some extent be admitted, that vegetables and small fruits grown upon sewage fields and presumably watered with sewage are liable to become contaminated with infectious materials. We must probably allow that lettuce, cabbages, radishes, strawberries and similar vegetables

or fruits, if so watered or flooded, may possibly become thus contaminated. On the other hand, the testimony of vital statistics in towns and cities in which such vegetables or fruits are consumed appears to be distinctly reassuring, and the advocates of sewage farming assert with much positiveness, that little or no apprehension need be felt in this direction. Probably the truth is that, in some countries very often, and in all countries in some cases, the disposal of sewage by irrigation is the most suitable method to be employed or recommended; but that in America, at least for the present, for the reasons stated above, or for other reasons peculiar to each locality, if land treatment of any kind is desirable or necessary, intermittent filtration is preferable.

§ 23. — *The Partial Purification of Sewage by Chemical Precipitation*

In the first report of the Commissioners appointed in 1868 to inquire into the best means of the preventing the pollution of rivers ("Mersey and Ribble Basins"), Vol. I, p. 51, 1870, the Commissioners introduce their discussion of this subject as follows: —

"The cleansing of sewage has engaged the attention of many chemists and others during the past ten or fifteen years; and various plans, some exhibiting great merit and ingenuity, have been proposed for dealing with the offensive liquid. . . . The valuable constituents of sewage present to the chemist a mine of wealth, which despite so many failures has constantly stimulated him to renewed efforts for their extraction in a portable and consequently marketable form.

"The chief valuable ingredients of sewage are, 1st, the different forms of combined nitrogen, and 2d, phosphoric acid. The money value of these constituents *dissolved* in one hundred tons of average sewage is about fifteen shillings, whilst the *suspended matters* contain only about two shillings' worth of them.

"There is but little difficulty in extracting the suspended matters by filtration, but as these do not contain quite one-seventh of the total valuable constituents, the process, though simple, has never been remunerative; and inasmuch as it still leaves much putrescible organic

matter in solution, the mere extraction of the suspended matters of sewage, although doubtless tending to mitigate nuisance, does not produce any substantial diminution of the polluting quality of the liquid. The operations of the chemist have, therefore, been directed chiefly to the soluble constituents of sewage; and have had for their object either the precipitation in a solid form of the valuable, but offensive, ingredients, so as to convert them into portable manure, or, secondly, the rendering them inoffensive by the action of disinfectants. Although these operations have not been altogether unsuccessful, they have hitherto entirely failed in purifying average sewage to such an extent as to render it admissible into running water. We have formed this opinion both from observations of the polluting effect of such chemically purified sewage upon the streams into which it was admitted, and from the amount of putrescible organic matter revealed by the chemical analyses of the sewage after treatment.

"It would obviously be rash to set any bounds to the possibilities of chemistry. Substances may, perhaps, be hereafter discovered capable of combining with and rendering insoluble the filthy constituents of our town drainage; but we are compelled to admit that the present resources of this science hold out no hope that the foul matters dissolved in sewage will be precipitated and got rid of by the application of chemicals to the offensive liquid. The chemical affinities of these foul matters are so feeble, and the matters themselves are dissolved in such enormous volumes of water, that their precipitation is a problem of extreme difficulty."—*Second Report, Rivers Pollution Commission of 1868*, pp. 18, 19. London, 1870.

These conclusions may fairly be taken as representative of the best expert opinion thirty years ago. In the meantime all attempts to make the chemical precipitation of sewage a source of pecuniary profit have been unsuccessful, and the most that is hoped for to-day is to keep the expense of the process within tolerable bounds. On the other hand, the sanitary results now obtained are decidedly better than those reported by the Rivers Pollution Commissioners in the quotations given above.

This method of sewage disposal is much used in England, either alone or in combination with disposal of the effluent by intermittent filtration or irrigation. The effluent is usually well clarified, and shows a removal of about nine-tenths of the suspended matters and one-half of the

total organic matters. Experience has shown that such an effluent can safely be admitted into a stream of relatively large size, provided it is not to be used for drinking purposes.

One of the most carefully conducted establishments for the disposal of sewage by chemical precipitation is that at Worcester, Mass., and the chemical examinations of the effluent, there constantly made, show an average reduction of 95 per cent of the suspended and about 53 per cent of the dissolved organic matters of the sewage. It is fair to state, however, that Worcester has been called upon to defend the process before the law on complaint of Millbury, a town below Worcester, on the Blackstone river into which the effluent from the Worcester purification plant is poured. Millbury has claimed that the purification of the effluent is inadequate, and that a nuisance which exists there is due to imperfect purification of the sewage of Worcester. On trial it appeared that there was among the most competent experts a great difference of opinion as to the sanitary efficiency of the process.

The reader who cares to pursue the subject of chemical precipitation further is referred to the following: Hazen, "Experiments on the Chemical Precipitation Sewage," Massachusetts Special Report, State Board of Health, 1890, p. 734. *Ibid.*, "Chemical Precipitation of Sewage at the World's Fair, Chicago, 1893." Massachusetts Report, 1892, p. 595. "Annual Reports" of H. P. Eddy, Superintendent of Sewers, City of Worcester, Mass. Baker and Rafter, "Sewage Disposal in the United States." (D. Van Nostrand Co.), New York.

§ 24.— *Sewage Disposal and Purification by Electricity*

The extensive development of electrical appliances has naturally led to various proposals for the purification of sewage by electrical means. It can hardly be said, how-

ever, as yet, that any of these has attained a practical importance such as would entitle it to consideration.

The principles involved in the electrical purification of sewage have been clearly stated, and the recent state of the subject ably summarized, by Professor (now President) Thomas M. Drown,[1] of Lehigh University, chemist to the State Board of Health of Massachusetts, in the following words: —

"We may distinguish two classes of so-called electrical purification: first, those which electrolyze water, liberating oxygen at the positive pole; and, second, those which electrolyze a solution of common salt and liberate chlorine in the same way.

"The Webster process for the purification of sewage, of which a good deal was once heard, belonged mainly to the first class, although by reason of the chlorides contained in the sewage it fell also, in part, into the second class. The oxygen liberated at the positive pole, while in the nascent state, was supposed to oxidize some organic matter; but as the pole was composed of iron plates, the oxygen was mainly consumed in oxidizing this iron, and the oxide of iron thus formed acted as a precipitating agent on the sludge in the sewage. The process was thus mainly one of chemical precipitation of sewage by means of oxide of iron, which was formed by a current of electricity passing through the sewage. . . .

"The possibility of oxidizing organic matter on the large scale by means of nascent oxygen liberated from water by the electric current will, probably, never be more than a dream. Attractive as the process seems, the necessary conditions for accomplishing it could probably never be realized on a city's water supply, or on its sewage. . . .

"The more recent systems of purification of water and sewage by electricity belong in the second class, that is, the decomposition by electrolysis of a solution of common salt. . . .

"The principal product, under ordinary conditions, is sodium hypochlorite. . . .

"This, then, sodium hypochlorite, is the substance with which we have to deal in the method of electrical purification which depends on the electrolysis of a solution of salt or sea water. When the current of electricity has, in the manner above described, formed a sufficiently concentrated solution of sodium hypochlorite, this solution is mixed with the water or sewage to be purified. . . .

[1] *Journal New England Water Works Association*, VIII (1894), pp. 183–188. "On the Electrical Purification of Water [and Sewage]."

"The so-called 'electrical' purification of water by treating it with an electrolyzed solution of salt is thus seen to be simply a process of disinfection by sodium hypochlorite; electricity, as such, has nothing to do with it. . . .

"Ozone is generally supposed to cover a multitude of sins of pollution, and quickly to destroy them; but we do not know much, if anything, about its germicidal power; and there is certainly no good reason for attributing any of the disinfecting action of an electrolyzed salt solution to ozone, even did we certainly know it to be present.

"It is unfortunate that the advocates of this system of purification of water and sewage are not content to attribute the purifying action of the electrolyzed solution of salt solely to the hypochlorite formed. There is nothing gained by calling it 'electrozone,' or an 'electro-saline solution,' for there is nothing mysterious about its action, as these terms would lead one to suppose. Nor is it proper to speak of this system of purification as in any sense an 'electrical' one. If one were to purchase two bottles of sodium hypochlorite of identically the same composition, one prepared by a chemical process and the other by the electrolysis of a salt solution, he would not expect to find them called by different names. To call the latter an 'electrical disinfectant' would be simply fantastic."

§ 25. — *Sewage Disposal and the Partial Self-Purification of Sewage by Means of Fermentation or Putrefaction.*

A recent and interesting development in the theory and practice of sewage disposal and purification is that known as the septic process, in which advantage is taken of the fact that sewage is a highly putrescible fluid richly charged with putrefactive bacteria, in order to decompose it by its own ordinary processes of bacterial fermentation or putrefaction, thus bringing it into a condition in which it is believed to be more readily nitrified when, subsequently, it is brought in contact with the living earth, and, in particular, causing suspended matters (sludge) to pass partly or wholly into solution.

The process consists simply in allowing ordinary town sewage to stagnate, ferment and putrefy in a tank or tanks for a somewhat longer time than usual. Under these circumstances, the sewage contains no free oxygen,

and Pasteur's original idea of fermentation as "life without air" is fully realized. According to the evidence of various observers, the organic matter is thus more thoroughly decomposed, and the sewage is more quickly brought into a condition in which it is readily nitrified when, as is the practice, it is afterward run through slow sand filters in the usual methods of intermittent filtration, or by the ingenious modification of intermittent filtration known as "contact filters" proposed by Dibdin. Further details and a full account of the various processes employed may be found in a valuable paper by Professor L. P. Kinnicutt, entitled "Purification of Sewage by Bacterial Methods," *Journal New England Water Works Association*, Vol. XV, p. 119. Boston, 1900. See also the "Annual Reports" of the Connecticut State Sewerage Commission, begun in 1899.

§ 26. — *Fate of the Infectious Matters in Sewage Disposal and Sewage Purification*

For the student of sanitary science, and from the practical point of view, it is a question of the highest importance what becomes of the infectious materials in sewage when the latter is disposed of, or purified, by any of the various methods described above.

In the case of disposal by dilution, there is reason to believe that much depends on the special conditions under which the dilution takes place. If, for example, a moderate amount of sewage is emptied into a relatively large body of quiet water, we may safely suppose that the infectious materials which it contains, namely, micro-organisms of various kinds, are for the most part unfavorably affected by the new environment with which they are likely to meet, and, under the influence of light, gravity, defective food supply and possibly predatory infusoria or other enemies, as well as unfavorable temperatures, gradually perish at a point not very distant from that at which they were dis-

charged. Indeed, it is impossible on any other hypothesis to explain the facts which have been observed in cases like those of Burlington, Cleveland, Chicago, Milwaukee, etc.

It is quite otherwise, however, with those cases of purification by dilution, in which the sewage forms a relatively large part of the body of the water into which it is emptied, and especially in those cases in which it is carried swiftly by running streams or currents within a short time to points comparatively remote from the place of disposal. In these cases, the same forces — light, gravity, temperature and, in general, unfavorable environment — would be operative, but yet the practical outcome might be that these were less availing, while the want of one other important element, time, would be favorable to the persistence of vitality of the micro-organisms which might therefore arrive, in a state of dilution to be sure, but yet, at comparatively remote points, quickly and therefore alive and virulent. It is for this reason that we are forced to conclude, contrary to the opinions held only a few years since, that quiet water, and not running water, purifies itself. But to this subject we shall return (in Chapter IX).

When we come to the disposal of sewage upon land, we find the question of the fate of infectious materials in the sewage entirely different. If, as is always assumed, the sewage to be purified is passed through, and not merely over, the earth, the micro-organisms which it contains are held back more or less completely, along with other suspended matters, by the living earth. One of the most striking phenomena of intermittent filtration which, as we have shown, is the fundamental process in all land treatment of sewage, is the disappearance of the very numerous living bacteria always present in the crude sewage. Some of these, no doubt, are mechanically detained in the upper layers of the living earth, the jelly-like masses which exist there being especially favorable for entanglement of their cilia. Others perish from lack of food, either near the surface or, more

probably, in the lower layers of the filter, or still further down, in the now purified effluent which has been robbed of the food materials but lately abundant in it. In the sewage filters at the Lawrence Experiment Station it very early became evident that a high degree of nitrification was accompanied by a remarkable disappearance of bacteria, and repeated experiments have shown that the effluent from a good sewage filter is incapable of supporting any considerable population of bacteria. There is no doubt that under certain circumstances bacteria applied to the surface of an intermittent filter may live to find their way into the effluent, as was proved for the first time at the Lawrence Experiment Station by experiments made in 1888 and published in 1890.[1] The same thing was shown a little later by the experiments of Fraenkel and Piefke,[2] and the fact is now generally accepted.

On the other hand, it is the universal testimony of those familiar with intermittent filters and sewage farms that the ordinary effluent waters derived from well-regulated filters may be, and often are, drunk with impunity. We do not know how small a number of pathogenic bacteria may under certain circumstances produce disease. But there is good reason to think that the danger of infection in any particular case depends, in part at least, upon the size of the dose, which would mean the number of micro-organisms introduced into the body. It is not claimed that sewage effluents are desirable for drinking waters; but there is very little doubt that the effluents from well-regulated filters or sewage farms may be safely introduced into streams or other bodies of water, even those which are later to be used as sources of water supply.

[1] "Experimental Investigations by the State Board of Health of Massachusetts on the Purification of Sewage and Water," 1888–1890, p. 852. Boston, 1890.

[2] *Zeit. für Hygiene*, 8, 1890. See also Bertschinger, *Vierteljahreschrift d. Naturforsch. Gesellsch. in Zürich*, 1889.

If it be asked, what becomes of the infectious materials held back by the soil? the answer is that they do not appear ordinarily to multiply, but rather to perish, along with the myriads of putrefactive bacteria which accompany them in the sewage. No fact is more striking in the history of the experimental filters at Lawrence than that these are vast charnel houses for bacteria. The sewage applied to the filters contains, on the average, one or two millions of bacteria per cubic centimetre. The effluent drawn off at the bottom contains at most only hundreds or thousands, and this state of affairs is continuous day after day, month after month and year after year. And yet, at the same time, there appears to be a living resident population, tolerably constant in numbers, distributed through the different layers of the filter. In view of this and similar facts, we have above referred to the earth as the home of the bacteria; but in view also of the enormous mortality of the bacteria in a sewage filter, it is equally clear that the earth may be no less truly their tomb; and it appears to be here that the infectious micro-organisms present in the sewage find, fortunately, in this particular form of sewage disposal, their last resting-place.

In the case of purification of sewage by chemical precipitation, we may reasonably suppose that most of the infectious materials are carried down by the precipitant and got rid of in the sludge. In any event, however, the fate of the infectious materials in this case is of less importance, inasmuch as effluents from chemical precipitation works are not, as a rule, and cannot safely be, at least in America, admitted into a body of water used for drinking purposes.

It has been urged in favor of the electrical purification of sewage that the infectious materials present are readily destroyed by the electric currents employed. But this, in view of various experiments touching the effect of electricity upon bacteria and other micro-organisms is, to say the

least, doubtful; and if what has been stated above in regard to the real nature of this method of purification is true, the problem here does not differ essentially from that affecting chemical precipitation, which has just been considered.

As to the effect produced by the natural, fermentation or septic, process, especially when combined with Dibdin's contact filters, such as are in use at Exeter and Manchester, in England, very little is as yet known; but it is fair to suppose that the fermenting process in the tank, in the absence of oxygen, as well as the nitrifying process in the filters in the presence of oxygen, are highly unfavorable to the continued life, and still less to the multiplication, of infectious materials. We may safely predict that these processes will prove to be entirely satisfactory so far as the purification of the sewage in respect to infectious matters is concerned.

CHAPTER VIII

ON WATER AS A VEHICLE OF INFECTIOUS DISEASE. THE POLLUTION OF PUBLIC WATER SUPPLIES. NOTABLE EPIDEMICS DUE TO INFECTED DRINKING WATER

"My reports are incessantly showing the foulness of private supplies while as regards public water supplies . . . it has again and again been shown that their conveniences and advantages are countervailed by dangers to life on a scale of gigantic magnitude." — SIR JOHN SIMON, *Ninth Report, Medical Officer of the Privy Council*, p. 34. London, 1867.

"The events I am going to relate to you would, in the Middle Ages, have been ascribed to some mysterious influence or to supernatural persecution. Science now enlightens us on the true cause of the evil, but at the same time imposes upon us the obligation to employ all the resources it gives us to combat the danger, which belongs to a class that human prudence can avoid." — DR. GUENEAU DE MUSSY, *on lead poisoning in the family of Louis Philippe from the water supply of the royal palace of Claremont.*

INASMUCH as sewage may contain any or all of the infectious materials from diseased animal bodies, and inasmuch, further, as it is a liquid readily miscible with water, — being itself hardly more than very dirty water, — while it is also produced in relatively large quantities by modern communities, it is perhaps not to be wondered at that the germs of disease often find access to wells, springs, reservoirs and streams, from which water is destined sooner or later to be drawn for drinking purposes.

§ 1.—*Drinking Water as a Vehicle of Disease*

It has been shown above (Chapter V) that while infectious materials may sometimes enter the body through the

skin, the more common and the easier avenues are those of the alimentary, pulmonary and genito-urinary tracts. Of all the substances admitted into the alimentary canal, the most abundant, and perhaps the most trusted, is water. The "cup of cold water" has long stood as the symbol of charity; and yet, from the sanitary point of view, there is little or no doubt that water is one of the most dangerous vehicles of disease which passes through the gates leading into the human body.

Water chemically pure should, of course, contain no infectious materials, although it is an interesting fact that in laboratory experiments it is possible to introduce into distilled water a considerable number of pathogenic bacteria without producing any effect upon the water discoverable by the most refined chemical analysis. Again, it is quite possible, in laboratory experiments, to mingle with a specimen of water millions of the germs of typhoid fever or Asiatic cholera without effecting perceptibly its bright and attractive appearance. With these facts in mind it becomes comparatively easy to understand that water may appear bright and attractive to the eye and be acceptable to the palate, while yet containing myriads of disease germs. It should not be forgotten, however, that what has been stated is true only of laboratory experiments, and rarely, if ever, happens or is likely to happen under natural conditions or on a large scale.

Natural waters, such as those of springs and wells, brooks and other streams from uninhabited districts, should contain, and ordinarily do contain, no infectious materials; and such waters, although they may contain mud, or various vegetable and even animal matters, are commonly described as "pure." But it is very different with natural waters which have been exposed to pollution, especially by sewage. From what has already been said it is clear that the latter may and frequently does contain infectious materials; so that if sewage in any form finds its way into drinking

waters, these are more than likely to prove a convenient vehicle for the conveyance of infectious materials into the human body. Even if sewage has been somewhat purified by dilution or other treatment, its presence in waters used for drinking properly constitutes a source of anxiety, the precise danger involved depending in any special case upon the degree of purification which they have undergone; and it is obvious that the determination of the degree of purification in any particular case of pollution may be a special problem taxing the best resources of the sanitarian.

§ 2.—*Diarrhœal Diseases and Drinking Water*

A little reflection will show that while diseases of the skin, the throat, the lungs, the nose, etc., are accompanied by eruptions, exudations, expectorations or other discharges which may find their way into sewage, these are usually insignificant in amount in comparison with the bowel discharges. It is not surprising, therefore, to learn that diseases affecting the alimentary canal, and especially the intestine, particularly if accompanied by diarrhœa, are most conspicuous among the diseases conveyed by sewage-polluted drinking water. It is now well established that certain bowel diseases, such as typhoid fever and Asiatic cholera, are readily conveyed by drinking water, and numerous epidemics of these diseases have been traced to infected water supplies; but there is very little evidence of the conveyance of diseases of the skin, throat, lungs and nose by this particular vehicle. Moreover, there are certain members even of the group of diseases known as "diarrhœal" which do not seem to be as readily conveyed by drinking water as are others of the same class. Cholera infantum, for example, is a common, severe and often fatal diarrhœal disease of children. But it seems seldom, if ever, traceable to polluted drinking water, with which typhoid fever and Asiatic cholera can very often be directly connected.

§ 3.—*Typhoid Fever and Asiatic Cholera*

These two diseases, and especially typhoid fever, are of preëminent importance and interest to the student of sanitary science, and for this reason a short account of their natural history will be given at this point as a preface to further consideration of them. As long ago as 1874 expert opinion had concluded that "the existence of specific poisons capable of producing cholera and typhoid fever is attested by evidence so abundant and strong as to be practically irresistible. These poisons are contained in the discharges from the bowels of persons suffering from these diseases."—*Rivers Pollution Commission of 1868, Sixth Report*, p. 427. London, 1874.

Typhoid fever is so called because it resembles, and was not formerly distinguishable from, typhus fever, otherwise known as "ship," "jail" or "spotted" fever. It is characterized by slow and insidious onset during a period lasting for about two weeks, and known as the "prodromal" period, during which the patient generally suffers from severe frontal headache, often having in addition backache, nose-bleed, diarrhœa and a general loss of strength which finally, in severe cases, compels him to take to his bed. By this time active fever is well established, the temperature ranging from 100° to 105° or even higher, and characterized by a daily rise in the evening and a fall in the morning. During the period of active sickness, which usually lasts from four to eight weeks, delirium sometimes occurs, and other serious symptoms make their appearance. It is a characteristic of the disease, and one which distinguishes it from typhus fever, that in typhoid fever the small intestine undergoes more or less extensive and dangerous ulcerations; and inasmuch as these ulcers burrow into the wall of the intestinal tube, they may either perforate it, allowing fæcal matters to enter the peritoneal cavity, and causing speedy death from septicæmia, or they may involve important blood

vessels, which becoming disintegrated cause profuse hemorrhages, often likewise followed by speedy death.

Owing to the fact that the lower animals are not, so far as known, susceptible to typhoid fever, it has never been possible, as yet, to establish with absolute certainty the identity of the specific germ of typhoid fever. At the same time there is a very general agreement that the so-called Koch-Eberth-Gaffky bacillus is, in all probability, the real and specific cause of the disease. The commonly accepted theory of the causation of typhoid fever is, that the specific bacilli, making their way into the alimentary canal in such vehicles as water, milk, dirt or dust, survive the journey through the stomach, and finding themselves in the intestine, there multiply and produce their own specific toxin, to the absorption of which are due the earlier symptoms of the disease. Simultaneously, or possibly subsequently, and presumably under the action of the same toxin, the guardian membranes of the alimentary tract are weakened or otherwise damaged, so that their usual resistance is somewhat enfeebled, and the bacilli make their way through them into the tissues of the body proper. Of all the tissues the spleen seems to be particularly affected; and it is from this organ that those bacilli are most easily recovered which are believed to be specific and characteristic of the disease.

If these commonly accepted ideas are correct, it is obvious that the bowel discharges of typhoid fever patients must naturally contain large numbers of the germs of typhoid fever; and that if these discharges find their way into sewage, such sewage must be not only polluted with the ordinary bowel discharges, but also actually infected with the specific germs of the disease. Furthermore, if this sewage happens to find its way into a water supply that supply is liable to become a vehicle of disease unless it shall somehow have been purified before it is used for drinking purposes. It should also be observed in pass-

ing that the journey from one human intestine to another may, conceivably at least, be very short, very direct and very quick; and it is also easy to understand that the virulence of the germs may well depend upon various conditions to which they have been submitted *en route*.

Asiatic cholera is a disease in many respects similar to typhoid fever, but more violent, more rapid and more fatal. In this case, also, owing to the insusceptibility of the lower animals to the disease, it has been thus far impossible to prove absolutely that the *Spirillum*, or *Vibrio*, generally regarded as the cause of the disease, is surely such. Certain experiments, voluntarily made by human beings, and a large amount of circumstantial evidence, have made it, however, highly probable that the general belief that we know the real germ of this disease is correct. (*Cf.* p. 98.)

In this case, also, it is held that the germs having been taken into the alimentary canal with food or drink or, possibly, air, survive the journey through the stomach, and, arriving in the intestine, there multiply enormously, producing at the same time their specific toxin, which, in cholera, is far more active and far more poisonous than that of typhoid fever. The toxin, being absorbed into the body proper, is supposed to cause those profound disturbances of the organism, and often even its rapid destruction, which are so characteristic of the disease.

In the case of typhoid fever it was until recently very difficult to demonstrate with certainty the presence of typhoid fever bacilli in the bowel discharges of patients suffering from that disease, so that we were actually in the humiliating position of attributing to these discharges the principal agency in the distribution of typhoid fever, while yet we were quite unable satisfactorily to prove the presence of the germs in the discharges. From this unfortunate dilemma we seem to have been relieved by the Widal serum test, so that at present it is held to be

easy to make the demonstration so desirable. In the case of Asiatic cholera, on the other hand, the number of micro-organisms present in the bowel discharges is so enormous that it has been from the start easy to demonstrate their existence; and there is no difficulty in understanding how it is that the bowel discharges of a single patient suffering from this disease may not only pollute, but also specifically infect, a particular specimen of sewage, with which, in turn, infection may pass into a water supply and, under certain conditions, arrive in the alimentary canal of a person drinking the infected water. Here, also, it is easy to follow the infection from one intestine to another, and, as in the case of typhoid fever, the extent and virulence of the infection will obviously depend upon a number of conditions *en route*, such as time, temperature, food supply, gravity, light and mechanical obstructions.

§ 4.—*An Epidemic of Asiatic Cholera traced to a Well. The Case of the Broad Street (London) Pump*

One of the earliest, one of the most famous, and one of the most instructive cases of the conveyance of disease by polluted water is that commonly known as the epidemic of Asiatic cholera connected with a Broad Street (London) well, which occurred in 1854. For its conspicuously circumscribed character, its violence and fatality, and especially for the remarkable skill, thoroughness and success with which it was investigated, it will long remain one of the classical instances of the terrible efficiency of polluted water as a vehicle of disease. As a monument of sanitary research, of medical and engineering interest and of penetrating inductive reasoning, it deserves the most careful study. No apology, therefore, need be made for giving of it here a somewhat extended account.[1]

[1] The complete original report is entitled "Report on the Cholera Outbreak in the Parish of St. James, Westminster, during the Autumn of 1854.

(a)—*The Parish of St. James, Westminster, in 1854*

The parish of St. James, Westminster (London), occupied in 1854, 164 acres, and contained in 1851, 36,406 inhabitants. It was divided into three subdistricts, viz., those of St. James's Square, Golden Square, and Berwick Street. As will be seen by the map (at p. 174), it was situated near a part of London now well known to travellers, not far from the junction of Regent and Oxford streets. It was bounded by May Fair and Hanover Square on the west, by All Souls and Marylebone on the north, St. Anne's and Soho on the east and Charing Cross and St. Martin's-in-the-Fields on the east and south.

In the cholera epidemics of 1832, 1848–1849, and 1853, St. James's Parish suffered somewhat but, on the average, decidedly less than London as a whole. In 1854, however, the reverse was the case. The Inquiry Committee estimated that in this year "the fatal attacks in St. James's Parish were probably not less than 700," and from this estimate computed a cholera death-rate, during 17 weeks under consideration, of 220 per 10,000 living in the parish, which was far above the highest in any other district. In the adjoining subdistrict of Hanover Square the ratio was 9; and in the Charing Cross district of St. Martin's-in-the-Fields (including a hospital) it was 33. In 1848–1849 the cholera mortality in St. James's Parish had been only 15 per 10,000 inhabitants.

(b)—*The Search for the Source of the Epidemic*

Within the parish itself the disease in 1854 was very unequally distributed. In the St. James's Square district the cholera mortality was only 16 per 10,000, while in the Golden Square district it was 217, and in the Berwick

Presented to the Vestry by the Cholera Inquiry Committee, July, 1855." London, J. Churchill, 1855.

Street district, 212. It was plain that there had been a special cholera area, a localized, circumscribed district. This was eventually minutely studied in the most painstaking fashion as to population, industries, previous sanitary history, meteorological conditions and other general phenomena common to London as a whole; with the result that it was found to have shared with the rest of London "a previous long-continued absence of rain . . .; a high state of temperature both of the air and of the Thames . . .; an unusual stagnation of the lower strata of the atmosphere, highly favorable to its acquisition of impurity . . .; and although it was impossible . . . to fix the precise share which each of the conditions enumerated might separately have had in favoring the spread of cholera, the whole history of that malady, as well as of the epidemic of 1854, and indeed of the plagues of past epochs, justifies the supposition that their combined operation, either by favoring a general impurity in the air or in some other way, concurred in a decided manner, last summer and autumn (1854), to give temporary activity to the special cause of that disease." (Report of Cholera Inquiry Committee, pp. 38, 39.) The Inquiry Committee did not, however, rest satisfied with these vague speculations and conclusions. ". . . But, as previously shown in the history of this local outbreak, the resulting mortality was so disproportioned to that in the rest of the metropolis, and more particularly to that in the immediately surrounding districts, that we must seek more narrowly and locally for some peculiar conditions which may help to explain this serious visitation."

Accordingly, special inquiries were made within the district involved in regard to its "elevation of site"; "soil and subsoil" (including an extended inquiry into the history of a "pest-field," said to have been located within this area in 1665–1666, to which some had attributed the cholera of 1854); "surface and ground plan"; "streets and

courts"; "density of population"; "character of the population"; "dwelling houses—internal economy as to space, light, ventilation and general cleanliness"; "dust-bins and accumulations in yards, cellars and areas"; "cesspools, closets and house-drains"; "sewers, their waterflow and atmospheric connection"; "public water supply"; and "well-water supply." No peculiar condition or adequate explanation of the origin of the epidemic was discovered in any of these, even after the most searching inquiry, except in the well-water supply. Abundant general defects were found in the other sanitary factors, but nothing peculiar to the cholera area, or, if peculiar, common to those attacked by the disease, could be found excepting the supply of well water.

(c)—*Suspicion falls upon the Broad Street Pump. The Investigations of Dr. John Snow.*

At the very beginning of the outbreak, Dr. John Snow, with commendable energy, had taken the trouble to get the number and location of the fatal cases, as is stated in his own report (Report of Cholera Inquiry Committee, pp. 100 *et seq.*):—

"I requested permission, on the 5th of September, to take a list, at the General Register Office, of the deaths from cholera registered during the week ending the 2d of September in the subdistricts of Golden Square and Berwick Street, St. James's, and St. Anne's, Soho, which was kindly granted. Eighty-nine (89) deaths from cholera were registered during the week in the three subdistricts. Of these only six (6) occurred on the first four days of the week; four (4) occurred on Thursday, August 31; and the remaining 79 on Friday and Saturday. I considered, therefore, that the outbreak commenced on the Thursday; and I made inquiry in detail respecting the 83 deaths registered as having taken place during the last three days of the week.

"On proceeding to the spot I found that nearly all the deaths had taken place within a short distance of the pump in Broad Street. There were only ten (10) deaths in houses situated decidedly nearer to another street pump. In five (5) of these cases the families of the deceased persons told me that they always sent to the pump in Broad Street, as they preferred the water to that of the pump which was nearer. In three other cases, the deceased were children who went to school near the pump in Broad Street. Two of them were known to have drunk the water, and the parents of the third think it probable that it did so. The other two deaths beyond the district which the pump supplies represent only the amount of mortality from cholera that was occurring before the eruption took place.

"With regard to the 73 deaths occurring in the locality belonging, as it were, to the pump, there were 61 instances in which I was informed that the deceased persons used to drink the water from the pump in Broad Street, either constantly or occasionally. In six (6) instances I could get no information, owing to the death or the departure of every one connected with the deceased individuals; and in six (6) cases I was informed that the deceased persons did not drink the pump water before their illness.

"The result of the inquiry consequently was that there had been no particular outbreak or increase of cholera in this part of London, except among the persons who were in the habit of drinking the water of the above-mentioned pump well.

"I had an interview with the Board of Guardians of St. James's Parish on the evening of Thursday, 7th of September, and represented the above circumstances to them. In consequence of what I said the handle of the pump was removed on the following day. . . .

"The additional facts that I have been able to ascertain are in accordance with those above related; and as regards

the small number of those attacked who were believed not to have drunk the water from the Broad Street pump, it must be obvious that there are various ways in which the deceased persons may have taken it without the knowledge of their friends. The water was used for mixing with spirits in some of the public houses around. It was used likewise at dining rooms and coffee-shops. The keeper of a coffee-shop which was frequented by mechanics, and where the pump water was supplied at dinner time, informed me on the 6th of September that she was already aware of nine of her customers who were dead."

On the other hand, Dr. Snow discovered that while a workhouse (almshouse) in Poland Street was three-fourths surrounded by houses in which cholera deaths occurred, out of 535 inmates of the workhouse only five (5) cholera deaths occurred. The workhouse, however, had a well of its own in addition to the city supply, and never sent for water to the Broad Street pump. If the cholera mortality in the workhouse had been equal to that in its immediate vicinity, it should have had fifty deaths.

A brewery in Broad Street employing seventy workmen was entirely exempt, but having a well of its own, and allowances of malt liquor having been customarily made to the employees, it appeared likely that the proprietor was right in his belief that resort was never had to the Broad Street well.

It was quite otherwise in a cartridge factory at No. 38 Broad Street, where about two hundred work-people were employed, two tubs of drinking water having been kept on the premises and always filled from the Broad Street well. Among these employees eighteen died of cholera. Similar facts were elicited for other factories on the same street, all tending to show that in general those who drank the water from the Broad Street well suffered either from cholera or diarrhœa, while those who did not drink that water escaped. The whole chain of evidence was made

absolutely conclusive by several remarkable and striking cases like the following: —

"A gentleman in delicate health was sent for from Brighton to see his brother at No. 6 Poland Street, who was attacked with cholera and died in twelve hours, on the 1st of September. The gentleman arrived after his brother's death, and did not see the body. He only stayed about twenty minutes in the house, where he took a hasty and scanty luncheon of rump steak, taking with it a small tumbler of cold brandy-and-water, the water being from Broad Street pump. He went to Pentonville, and was attacked with cholera on the evening of the following day, September the 2d, and died the next evening."

"The deaths of Mrs. E—— and her niece, who drank the water from Broad Street at the West End, Hampstead, deserve especially to be noticed. I was informed by Mrs. E——'s son that his mother had not been in the neighborhood of Broad Street for many months. A cart went from Broad Street to West End every day, and it was the custom to take out a large bottle of the water from the pump in Broad Street, as she preferred it. The water was taken out on Thursday, the 31st of August, and she drank of it in the evening and also on Friday. She was seized with cholera on the evening of the latter day, and died on Saturday. A niece who was on a visit to this lady also drank of the water; she returned to her residence, a high and healthy part of Islington, was attacked with cholera, and died also. There was no cholera at this time, either at West End or in the neighborhood where the niece died. Besides these two persons only one servant partook of the water at West End, Hampstead, and she did not suffer, or, at least, not severely. She had diarrhœa."

Dr. Snow's inquiry into the cases of cholera which were nearer other pumps showed that in most the victims had preferred, or had access to, the water of the Broad Street well, and in only a few cases was it impossible to trace

any connection with that pump. Finally, Dr. Snow made a statistical statement of great value, which is here given in its original form.

THE BROAD STREET (LONDON) WELL AND DEATHS FROM ASIATIC CHOLERA NEAR IT IN 1854

Date	Number of Fatal Attacks	Deaths	Date	Number of Fatal Attacks	Deaths
August 19 . .	1	1	Sept. 11 . . .	5	15
" 20 . .	1	0	" 12 . . .	1	6
" 21 . .	1	2	" 13 . . .	3	13
" 22 . .	0	0	" 14 . . .	0	6
" 23 . .	1	0	" 15 . . .	1	8
" 24 . .	1	2	" 16 . . .	4	6
" 25 . .	0	0	" 17 . . .	2	5
" 26 . .	1	0	" 18 . . .	3	2
" 27 . .	1	1	" 19 . . .	0	3
" 28 . .	1	0	" 20 . . .	0	0
" 29 . .	1	1	" 21 . . .	2	0
" 30 . .	8	2	" 22 . . .	1	2
" 31 . .	56	3	" 23 . . .	1	3
Sept. 1 . .	143	70	" 24 . . .	1	0
" 2 . .	116	127	" 25 . . .	1	0
" 3 . .	54	76	" 26 . . .	1	2
" 4 . .	46	71	" 27 . . .	1	0
" 5 . .	36	45	" 28 . . .	0	2
" 6 . .	20	37	" 29 . . .	0	0
" 7 . .	28	32	" 30 . . .	0	0
" 8 . .	12	30	Date unknown .	45	0
" 9 . .	11	24			
" 10 . .	5	18	Total . . .	616	616

(*d*)—*The Rev. Mr. Whitehead's Detailed Studies of Broad Street and Its Pump*

In addition to the original and general inquiry conducted from the time of the outbreak by Dr. Snow, the Rev. H. Whitehead, M.A.,[1] curate of St. Luke's in Berwick Street,

[1] "The Rev. H. Whitehead, M.A., to whom medicine is in a great measure indebted for that elaborate investigation of the cholera outbreak in the parish of St. James, Westminster (the Broad Street pump outbreak), which it is now known gives to Dr. Snow's opinion of its origin a probability

and like Dr. Snow, a member of the Cholera Inquiry Committee, whose knowledge of the district both before and during the epidemic, owing to his official position, gave him unusual advantages, made a most elaborate and painstaking house-to-house investigation of one of the principal streets affected, viz., Broad Street itself. Mr. Whitehead's report, like that of Dr. Snow, is a model of careful and extended observation and study, cautious generalizing and rigid verification. It is an excellent instance of inductive scientific inquiry by a layman in sanitation. Mr. Whitehead found the number of houses on Broad Street, 49; the resident householders, 35; the total number of resident inhabitants, 896; the total number of deaths among these, 90. Deaths among non-residents (workmen, etc.) belonging to the street, 28. Total deaths chargeable to this street alone, 118. Only 10 houses out of 49 were free from cholera. The dates of attack of the fatal cases resident in this single street were as follows:—

Date of Attack	Number of Fatal Attacks	Date of Attack	Number of Fatal Attacks
August 12	1	Sept. 4	8
" 28	1	" 5	6
" 30	1	" 6	5
" 31	6	" 7	0
Sept. 1	26	" 8	2
" 2	24	" 9	1
" 3	9		90

Mr. Whitehead's detailed investigation was not made until the spring of 1855, but in spite of this fact it supplied most interesting and important confirmatory evidence of Dr. Snow's theory that the Broad Street well was the source of the epidemic. Mr. Whitehead, moreover, went further

practically amounting to a demonstration."—MR. J. NETTEN RADCLIFFE, "On Cholera in London in 1866," *Ninth Rep. Med. Officer of the Privy Council*, p. 288.

than Dr. Snow, and endeavored to find out how the well came to be infected, why its infectious condition was so limited as it appeared to have been, and to answer various other questions which occurred in the course of his inquiry. As a result, he concluded that the well must have been most infected on August 31; that for some reason unknown a partial purification began on September 2, and thereafter proceeded rapidly. There was some evidence that on August 30 the water was much less infected than on the 31st, so that its dangerous condition was apparently temporary only. He further discovered that in the house No. 40 Broad Street, which was the nearest house to the well, there had been not only four fatal cases of cholera contemporaneous with the epidemic, but certain earlier cases of an obscure nature, which might have been cholera, and that dejecta from these had been thrown without disinfection into a cesspool very near to the well. On his reporting these facts, in April, 1855, to the main committee, Mr. J. York, secretary and surveyor to the committee, was instructed to survey the locality and examine the well, cesspool and drains at No. 40 Broad Street.

(*e*) *Survey and Description of the Broad Street Well and its Surroundings*

Mr. York's report revealed a startling condition of affairs. The well was circular in section, 28 ft. 10 in. deep, 6 ft. in diameter, lined with brick, and when examined contained 7 ft. 6 in. of water. It was arched in at the top, dome fashion, and tightly closed at a level 3 ft. 6 in. below the street, by a cover occupying the crest of the dome.

The bottom of the main drain of the house No. 40 Broad Street lay 9 ft. 2 in. above the water level, and one of its sides was distant from the brick lining of the well only 2 ft. 8 in. It was —

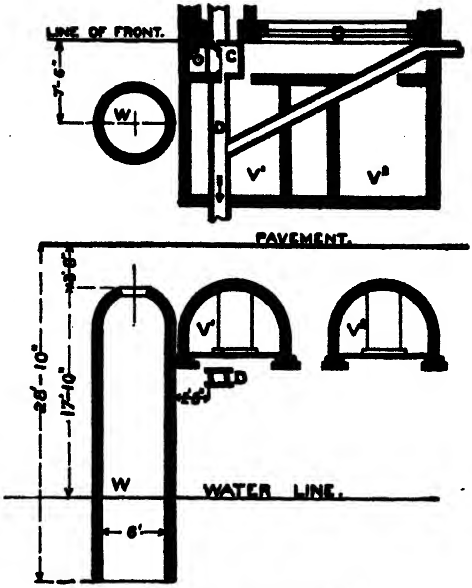
"constructed on the old-fashioned plan of a flat bottom, 12 in. wide, with brick sides rising about 12 in. high, and covered with old stone.

As this drain had but a small fall, or inclination outward to the main sewer, the bottom was covered with an accumulation of soil deposit about 2 in. thick; and upon clearing this soil away the mortar joints of the old stone bottom were found to be perished, as was also all the jointing of the brick sides, which had brought the brick work into the condition of a sieve, and through which the house drainage water must have percolated for a considerable period. . . .

"After opening back the main drain, a cesspool intended for a trap, but misconstructed, was found in the area, 3 ft. 8 in. long, by 2 ft. 6 in. wide, and 3 ft. deep; and upon or over a part of this cesspool a common open privy (without water supply), for the use of the house, was erected, the cesspool being fully charged with soil. This privy was formed across the east end of the area, and upon removing the soil the brickwork of the cesspool was found to be in the same decayed condition as the drain, and which may be better comprehended by stating that the bricks were easily lifted from their beds without any, the least, force; so that any fluid could readily pass through the work, or, as was the case when first opened, over the top course of bricks of the trap, into the earth or made ground immediately under and adjoining the end wall eastward, this surface drainage being caused by the accumulation of soil in, and the misconstruction of, the cesspool. . . .

"Thus, therefore, from the charged condition of the cesspool, the defective state of its brickwork, and also that of the drain, no doubt remains upon my mind that constant percolation, and for a considerable period, had been conveying fluid matter from the drains into the well; but lest any doubt should arise upon this subject hereafter, I had two spaces of the brick steining, 2 ft. square each, taken out of the inside of the well — the first 13 ft. deep from the level of the street paving, the second 18 ft. deep, and a third was afterward opened still lower, when the washed appearance of the ground and gravel fully corroborated the assumption. In addition thereto, the ground was dug out between the cesspool and the well to 3 ft. below the bottom of the former, and its black, saturated, swampy condition clearly demonstrated the fact, as did also the small furrowed appearance of the underlying gravel observed from the inside of the well, from which the fine sand had been washed away during the process of filtration." —*Report of J. York, Secretary and Surveyor to the Cholera Inquiry Committee.*—*L. c.*

It was thus established, as clearly as can be done by circumstantial evidence, that the great epidemic in St. James' Parish, Westminster, London, in 1854, was caused by the polluted water of the Broad Street well, which for a



ASIATIC CHOLERA
AND
THE BROAD STREET WELL.
LONDON 1854.

W. . . . . . . WELL.
D. . . . . . . MAIN DRAIN OF HOUSE NO. 40.
V^1 AND V^2. . CELLARS UNDER STREET.
C. . . . . CESSPOOL.
P. . . . . PRIVY.
(AFTER MR. YORK'S ORIGINAL DRAWINGS.)

very few days was probably infected with cholera germs. It is much less clear how the well became infected, but it seems probable that the dejecta of a cholera patient found tolerably direct access to the well from the cesspool or drain of a house near by. There is no evidence whatever that the germs multiplied in the well, but rather much evidence that they rapidly died out. It is repeatedly stated in the report that the water was preferred for drinking because it was "cold," *i.e.* colder than the cistern water derived from the public water supply, and this condition would probably favor such dying out.

That the water had long been polluted, there can be no doubt. There was evidence of this, and also some evidence that it was worse than usual at the time when it was probably infected. One consumer spoke of it as having been at that time "offensive" in taste or odor. It is instructive to note that mere pollution seems to have done no obvious harm. Specific infection, however, produced Asiatic cholera.

Mr. Whitehead, in his singularly fair and candid report, raises an interesting question, viz., why, if an early and unrecognized case in the house in question brought about infection of the well, should not the four severer cases of undoubted cholera subsequently in the same house, with no known change in the drainage, have produced even greater disaster? This question remains unanswered, except that after the removal of the pump handle on the 8th of September access to the well was shut off, and during the intermediate week the well may have been avoided by the frightened people; or, owing to illness, less water may have been used in No. 40 Broad Street, so that the cesspool did not overflow; or some other condition, unknown, may have been changed.

§ 5.—*An Epidemic of Asiatic Cholera in London in 1866 traced to a Polluted and Infected Surface Water Supply*

Dr. John Snow, in 1854, gave it as his opinion that not only wells but also public water supplies of far more general distribution, such as those furnished by cities or corporations and derived from rivers, may, under certain circumstances, be carriers of cholera. The great epidemics of Asiatic cholera in London in 1832, 1848–1849 and 1853–1854 had so strongly enforced this idea that in dealing with an important problem raised by epidemic cholera in London in 1866 Mr. J. Netten Radcliffe states that, "The predominant lesson derived from the outbreaks of 1848–1849 and 1853–1854 was that the localities of chief prevalence of the disease were mainly, if not solely, determined by the degree of impurity of the water supply." [1]

In 1866 Asiatic cholera, having again become epidemic in London, appeared in marked abundance in certain eastern districts of the city. A special investigation of its origin and distribution in those parts was made for the medical officer of the Privy Council (Mr., afterward Sir, John Simon), by Mr. J. Netten Radcliffe, whose very elaborate and painstaking report (published *in extenso* in the Ninth Report, London, 1867) served to fasten the blame for the excess in East London upon a special pollution and infection of a portion of the public water supply of the district, derived from the river Lea.[2]

Briefly stated, it may be said that the epidemic of 1866

[1] Ninth Rep. Med. Officer of the Privy Council, p. 295. See also Simon, Report on the Cholera Epidemics of London in 1848–1849 and 1853–1854 as affected by the Consumption of Impure Water. London, 1856.

[2] Like some more recent students of English sanitation, Mr. Radcliffe seems to have been puzzled in regard to the correct spelling of this word. His note on the subject is therefore interesting. "The Rivers Pollution Commissioners have spelled the name of this river *Lee*. All the standard maps and geographical works of reference spell the name Lea. I have adhered to the orthography commonly used." — *Op. cit.*, p. 280.

in England began on April 28 with a case in Bristol imported from Rotterdam. By May 15 the disease was prevailing among certain emigrants on board ships in the Mersey bound for New York. These emigrants had recently come from infected places on the continent. Scattered cases or outbreaks soon began to be reported from various parts of England, such as Swansea and Southampton. The first death reported in London, according to Mr. Simon, was on July 18, and two days later an alarming number of cases appeared in East London. By July 21 it was clear that a special epidemic was prevailing in that region, and it is this special outbreak or "explosion" of cholera which forms the subject of Mr. Radcliffe's report. During the three months, — July, August and September, — there were registered in all England 10,365 deaths from cholera and 9570 deaths from diarrhœa. During the seven days ending August 4 there were in London alone 1053 deaths from cholera, and on one day (August 1) 204. The following comparison given by Mr. Radcliffe of the duration and mortality of the cholera epidemics in London in 1849, 1854, and 1866 is noteworthy: —

Epidemic of	Duration	Deaths from Cholera	Ratio to 10,000 Inhabitants	Deaths from Diarrhœa	Ratio to 10,000 Inhabitants
1849	23 weeks	13,565	51	2926	13.0
1854	23 weeks	10,684	43	2551	10.1
1866	23 weeks	5,548	18	2692	8.8

"Cholera having been so less fatal in proportion to the number of persons attacked by the disease [in 1866] . . . the foregoing results would indicate increased, and perhaps increasing, safeguards in the metropolis." — *Op. cit.*, p. 277. Mr. Radcliffe's investigation soon showed, however, that further safeguards, at least in respect to water supply, were urgently needed.

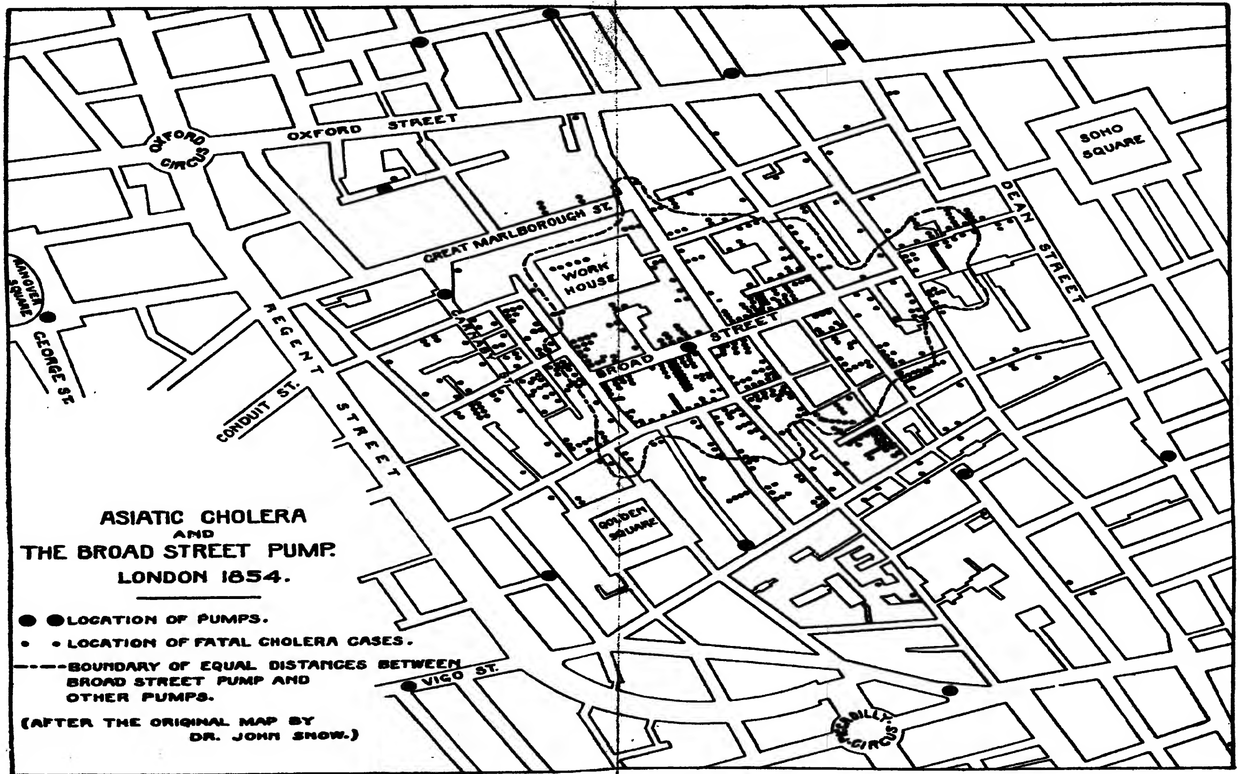
Of the whole number of cholera deaths (5548), 3909 occurred in the east districts—"more than double the amount distributed over the rest of the metropolis." Moreover, it was in these districts that it increased most rapidly and to the highest point, and that it fell off afterward most quickly. Again, "no relative development of like magnitude, suddenness, and shortness of duration had occurred in previous outbreaks of cholera in the metropolis," either in these or other districts. The brunt of the malady in 1849 and 1854 had fallen upon the south districts.

"London was unquestionably less filthy at the time of the outbreak than in any previous outbreak. But the east districts could not claim a preëminence of filth. In the west of the metropolis and south of the river there were many localities as filthy. Neither Rotherhithe, nor Bermondsey, nor Southwark, nor Westminster, can be compared favorably with the east of London, yet the three former places suffered in a trifling degree as compared with the latter."—*Op. cit.*, p. 293.

Mr. Radcliffe carefully considered, in addition to "filth," such possible or supposed causes of cholera as "soil," "density of population," "sewerage," "locality," "meteorological states" and "altitude," and concluded that "not one of the conditions named . . . and believed to be liable to affect the progress and development of epidemic cholera, the disease being present, will account for more than very limited fluctuations of the outbreak, or for its localization in any particular spot in a restricted degree only. Any combination of these conditions is, moreover, equally inefficacious in explaining the peculiar localization and fluctuation in the east districts of the metropolis."

(*a*)—*Suspicion directed to the Public Water Supply of the Infected District*

The water supply alone remained to be considered, and "from the commencement of the localization of cholera in



ASIATIC CHOLERA
AND
THE BROAD STREET PUMP.
LONDON 1854.

● LOCATION OF PUMPS.
• LOCATION OF FATAL CHOLERA CASES.
---- BOUNDARY OF EQUAL DISTANCES BETWEEN BROAD STREET PUMP AND OTHER PUMPS.

(AFTER THE ORIGINAL MAP BY DR. JOHN SNOW.)

the east districts the probable association of this circumscription with an impure water supply was forced upon the mind. . . . During the week ending the 28th of July it became obvious that the brunt of the outbreak had fallen upon the east districts; and in the bill of mortality for the week the registrar general directed attention to the fact that the field of prevalence of the disease was supplied with water from the East London Water Company's works." On August 1 the water company was notified that its supply was under suspicion, and the local sanitary authorities were recommended by Mr. Simon to issue the following:—

CHOLERA. NOTICE!

> "The inhabitants of the District within which Cholera is prevailing are earnestly advised *not to drink any water which has not previously been boiled. . . .*"

Further investigation satisfied Mr. Radcliffe that the "explosion" of cholera, which occurred just prior to July 21, had its origin in a temporary and limited infection of one portion of the East London Company's waterworks situated at Old Ford, on the river Lea. This river, considerably polluted by sewage in its upper reaches, was subjected to subsidence and filtration above, and at, Lea Bridge, respectively. Some of the filtered water was distributed from this point, and no blame was attached to this portion of the supply. The remainder was conveyed farther into the metropolis by a closed iron conduit, to two covered reservoirs on the west bank of the Lea at Old Ford, and from this point pumped into the distributing mains. On the east side of the river at Old Ford were two uncovered reservoirs of large capacity, one of which had, at the time of the outbreak, direct connection with the covered reservoirs of filtered water. The open reservoirs were also

connected with the filtering beds at Lea Bridge by an open and foul conduit, and they sometimes received the waste water from them unfiltered. They seem to have served as a reserve of unfiltered water to draw upon in case of clogging of the filter beds or in case of fire.

It was admitted that the filter beds had, in fact, been seriously clogged just before the cholera outbreak, and it was in evidence that on at least one occasion, early in July, some 300,000 gallons of unfiltered water had been drawn from one of the uncovered reservoirs into the covered reservoirs, to make good a deficiency in filtered water due to clogging of the filters. Precisely how this unfiltered and impure water may have become infected by choleraic poison is not known. Mr. Radcliffe believed that soakage from the river, which was known to have been infected in its lower reaches, probably found access to the open reservoir. This is certainly possible, but it seems more likely that the infection may have found direct access to the river in the unpurified sewage of some city or town on the upper watershed above the point of intake of the East London Company's works. "In its course it (the river Lea) drains about 570 square miles of country, and before reaching Enfield Lock . . . it receives the sewage of upward of 150,000 souls. It receives in its course, also, as affluents, several smaller streams, each in its degree a recipient of sewage." — *Op. cit.*, p. 296.

The medical officer of the Privy Council, in his historical summary of the progress of the disease in England, states that even "within the next few days" after May 15 two cases were reported at Swansea, "and single cases in various other parts of the country." Of early July he writes, "evidently England was now being infected in many different directions. Reports of new centres of infection became more and more frequent." It is not difficult to suppose that some one or more obscure case, or cases, may have occurred at this time or afterward upon the watershed

of the Lea, and thus have directly infected that river, polluted as it plainly was with unpurified sewage.

(*b*)—*The Obvious Value of Filtration as a Sanitary Safeguard*

On any hypothesis the supreme value and importance of filtration became manifest, for it was evidently only the unfiltered river water which did harm. The supply pumped from Lea Bridge was of filtered water derived from a highly polluted, and probably infected, river, and yet seems to have caused no spread of the disease.

This apparently logical conclusion as to the value of filtration was, nevertheless, laid open to serious question a few years later, in consequence of the famous Lausen epidemic, to a consideration of which we may now turn.

§ 6.—*An Epidemic of Typhoid Fever in Lausen, Switzerland, due to an Infected Ground Water or Spring*

Typhoid fever derived from impure drinking water is now recognized as of common occurrence, and a great number of destructive epidemics have been traced to this source. The first to attract universal attention was that which occurred in Lausen, Switzerland, in 1872; and because of certain peculiar conditions connected with it, and especially because of its influence upon the theory and practice of the purification of water by filtration, it deserves the most careful consideration by all students of sanitation.

The epidemic occurred in the little village of Lausen in the canton of Basel in Switzerland in August, 1872. Lausen was a well-kept village of 90 houses and 780 inhabitants, and had never, so far as known, suffered from a typhoid epidemic. For many years it had not had even a single case of typhoid fever, and it had escaped the cholera even when the surrounding country suffered from it. Suddenly, in August, 1872, an outbreak

of typhoid fever occurred, affecting a large part of the entire population.

A short distance south of Lausen was a little valley, the Fürlerthal, separated from Lausen by a hill, the Stockhalden, and in this valley, on June 19, upon an isolated farm, a peasant, who had recently been away from home, fell ill with a very severe case of typhoid fever, which he had apparently contracted during his absence. In the next two months there occurred three other cases in the neighborhood, — a girl, and the wife and the son of the peasant.

No one in Lausen knew anything of these cases in the remote and lonely valley when suddenly, on August 7, ten cases of typhoid fever appeared in Lausen, and by the end of nine days, fifty-seven cases. The number rose in the first four weeks to more than one hundred, and by the end of the epidemic in October to about 130, or seventeen per cent of the population. Besides these, fourteen children who had spent their summer vacation in Lausen fell ill with the same disease in Basel. The fever was distributed quite evenly throughout the town, with the exception of certain houses which derived their water from their own wells and not from the public water supply. Attention was thus fixed upon the latter, which was obtained from a well or spring at the foot of the Stockhalden hill on the Lausen side. The well was walled up, covered and apparently protected, and from it the water was conducted to the village, where it was distributed by several public fountains. Only six houses used their own wells, and in these six there was not a single case of typhoid fever, while in almost all the other houses of the village, which depended upon the public water supply, cases of the disease existed. Suspicion was thus directed to the water supply as the source of the typhoid poison, very largely because no other source could well be imagined. A distribution of the disease from the farm through the air was hardly conceivable because houses in the Fürlerthal, although lying upon the same plateau and

naturally more accessible through the atmosphere, remained free from the disease, a fact which seemed to prove that the infected farmhouse could not have communicated the disease to Lausen either through the ground water or through the air.

In order, however, to clinch the evidence that the Lausen water supply had been infected, it became desirable to show some source from which an infection, so unusual and remarkable, could have come, and precisely how it had happened. There had long been a belief that the Lausen well or spring was fed by and had a subterranean connection with a brook (the Fürler brook) in the neighboring Fürler valley; and since this brook ran near the peasant's house and was known to have been freely polluted by the excreta of the typhoid fever patients, absolute proofs of the connection between the well of Lausen and the Fürler brook could not fail to be highly suggestive and important. Fortunately such proofs were not far to seek. Some ten years before, observations had been made which had showed an intimate connection between the brook and the well. At that time, without any known reason, there had suddenly appeared near the brook in the Fürler valley below the hamlet, a hole about eight feet deep and three feet in diameter, at the bottom of which a considerable quantity of clear water was flowing. As an experiment, the water of the little Fürler brook was at that time turned into this hole, with the result that it had all flowed away underground and disappeared, and an hour or two later the public fountains of Lausen which, on account of the dry weather prevailing at the time, were barely running, had begun flowing abundantly. The water from them, which was at first turbid, later became clear; and they had continued to flow freely until the Fürler brook was returned to its original bed and the hole had been filled up. But every year afterward, whenever the meadows below the site of the hole were irrigated or overflowed by the waters of the brook, the Lausen fountains

soon began to flow more freely. In the epidemic year (1872) the meadows had been overflowed as usual from the middle to the end of July, which was the very time when the brook had been infected by the excrements of the typhoid patients. The water supply of Lausen had increased as usual, had been turbid at the beginning and had had a disagreeable taste. And about three weeks after the beginning of the irrigation of the Fürler meadows, typhoid fever had broken out, suddenly and violently, in Lausen.

In order to make matters, if possible, more certain, the following experiments were made, but unfortunately not until the end of August when the water of the Lausen supply had again become clear. The hole which had appeared ten years earlier, and had afterward been filled up, was reopened, and the little brook was once more led into it; three hours later the Lausen fountains were yielding double their usual volume. A quantity of brine containing about eighteen hundred pounds of common salt was now poured into the brook as it entered the hole, whereupon there appeared very soon in the Lausen water, first a small, later a considerable and finally a very strong, reaction for chlorine, while the total solids increased to an amount three times as great as before the brine was added. In another experiment, five thousand pounds of flour (*Mehl*), finely ground, were likewise added to the brook as it disappeared in the hole; but this time there was no increase of the total solids, nor were any starch grains detected in the Lausen water.

It was naturally concluded from these experiments that while the water of the brook undoubtedly passed through to Lausen and carried with it salts in solution, it nevertheless underwent a filtration which forbade the passage of suspended matters as large as starch grains. Dr. Hägler, from whose report the foregoing facts are taken, was careful, however, to state that "it is not denied that small organized

particles, such as typhoid fever germs, may nevertheless have been able to find a passage." As a matter of fact Dr. Hägler's minute account does to-day give us some indication that such germs might easily have passed from the brook to Lausen, for the turbidity of which he repeatedly speaks is evidence of the passage of particles probably as small as, and possibly smaller than, the germs of typhoid fever. (*Typhus und Trinkwasser, Vierteljahrschrift für öffentliche Gesundheitspflege, VI*, 154; also Sixth Report, Rivers Pollution Commission of 1868. London, 1874.)

Unfortunately, this was before pure cultures of bacteria were known, and no experiments were made with suspended matters as small as bacteria. The conclusion was inevitable that although filtration had in this case sufficed to remove starch grains, it had been powerless to remove the germs of typhoid fever; and, accordingly, filtration as a safeguard against disease in drinking water fell for a time into disrepute.[1]

§ 7.—*An Epidemic of Typhoid Fever in Caterham and Red Hill (England) traced to a Polluted and Infected Ground Water Supply*

A number of epidemics of typhoid fever had been already traced with more or less certainty to polluted water supplies when, in 1879, there appeared a serious outbreak of this disease in the towns of Caterham and Red Hill in England. The duty of investigation of this case was fortunately assigned to Dr. Thorne-Thorne, and his report which appears in the Report of the Medical Officer of the Local Government Board for 1879, pp. 78–92, is a model of careful investigation and sound reasoning. Briefly summarized, it was as follows: The total number of cases affected

[1] See a paper by the author on *The Rise and Progress of Water-Supply Sanitation in the Nineteenth Century.* Journal New England Water Works Association, XV (1901), p. 330, No. 4.

during the epidemic proper was 352. The total number of deaths, 21. The disease was typical typhoid fever, the patients exhibiting the characteristic rose-spots and diarrhœa and some of them suffering from severe pulmonary and intestinal complications, the latter including perforation of the bowels which, in four cases, was the immediate cause of death. The first person attacked sickened on January 19, 1879; a second, on the 20th; two more on the 23d; three on the 24th, and thenceforward up to February 2, to which date information was at first limited, fresh attacks in fresh houses occurred day by day.

Caterham lies in the rural sanitary district of Godstone, and had a population of about 5800. It included at this time a portion called Lower Caterham, near the head of the Caterham valley, a valley bounded by chalk hills. The houses in this part consisted mainly of superior villa residences. The other or upper part lies at a higher altitude. Here, also, are a number of villas, one of the asylums belonging to the Metropolitan District Asylums Board, and certain barracks.

The cases of typhoid fever referred to, and which had occurred in the fortnight ending February 2, were spread over a very wide area, some in Upper and some in Lower Caterham, extending to the extreme outskirts of both places. The families attacked belonged to no special class, both rich and poor having suffered. It was apparent that the disease could not have been conveyed by means of any general system of sewers for the majority of the houses drained into separate cesspools. There was also no possibility that there had been any common cause of infection in connection with the prevailing means of excrement disposal, because there was nothing in common with regard to such disposal. The possibility of infection by means of milk supply was next inquired into, but disproved. It was also evident that personal infection could not in any way have led to the outbreak. Finally, it was

stated that for some years past the locality had been remarkably free from the disease, and only one isolated case could be heard of as having occurred during the twelve months preceding the outbreak, and this case was believed to have been imported.

Caterham was supplied with water by the Caterham Waterworks Company, and of the forty-seven persons attacked during the fortnight in question, forty-five resided in houses supplied with this water. Suspicion was thus directed to the water supply, and was confirmed when it was ascertained that the two remaining patients, though living on premises having private wells, had been in the habit of spending the day at houses supplied with the company's water, and had admittedly used this water.

It further appeared that in the Caterham Asylum, having nearly two thousand patients, no typhoid fever had appeared, and that there had been a similar absence of the disease among the five hundred men in the barracks. Both these establishments derived their entire water from a well sunk 462 feet into the chalk.

In the meantime, information arrived that typhoid fever was also epidemic in Red Hill, a neighboring community. Red Hill had an estimated population of 9500, and included two or more villages, besides an asylum for idiots. It was about eight miles distant from Caterham, lay on a different geological formation, and was well sewered. Nevertheless, in regard to typhoid fever, the two places were remarkably similar. In both, the epidemic began at about the same time. The first two cases in Red Hill occurred on January 20; three more on the 21st; five more on the 22d; twelve on the 23d, and at the end of the first fortnight, namely, by February 2, the total number of houses affected was 96, and the number of patients had reached 132. There was nothing which threw suspicion upon the sewers. The community had been totally free from

the disease for at least eighteen months, and there was no reason to suspect the milk supply. The water supply, on the other hand, was derived for the most part from the waterworks of the Caterham Waterworks Company, and a sanitary official, Mr. Jacob, independently of Dr. Thorne and the local officer in Caterham, had arrived at the conclusion that the Caterham water was in all probability the vehicle of the disease. Of the ninety-six houses affected during the first fortnight of the epidemic at Red Hill, ninety-one actually drew their water from the Caterham Company's mains, and the histories obtained with reference to the attacks in the remaining five cases were such as to confirm the impression that the Caterham Company's water had been the immediate cause of the epidemic. For example, at one of these houses where ultimately three persons were attacked, the supply, as was hitherto believed, had been exclusively derived from a rain water tank, but it was now ascertained that the Caterham Company's water was in addition procured surreptitiously; that at another house, for which there was apparently no water supply, the company's water was procured from a neighbor's; and with regard to the remainder, the patients infected were not only persons who were employed where the company's water was in use, but several of them had partaken of the water at their meals.

Certain localities in Red Hill, namely, Meadvale, having about 160 houses, and in Red Hill itself a group of 30 houses supplied with wells, were practically exempt from typhoid fever. Still more striking was the case in Reigate, a town which forms the western ward of the burough of which Red Hill is the eastern ward. Reigate had a population of about 8500, provided, however, with a different water supply; and this region escaped entirely, only two cases, undoubtedly imported from Red Hill, having occurred there.

All the facts ascertained in connection with the course

of the epidemic up to February 2 afforded very strong presumption that it had been caused by the use of the Caterham Company's water. Further developments made this view almost certain.

The Waterworks Company derived its supply from two deep wells, situated about 30 feet apart, and about 490 feet deep. Both were several feet in diameter. Moreover, they were connected, by three adits in the chalk. From the wells the water was pumped to reservoirs, in which it was submitted to Clark's softening process. The reservoirs freely communicated, and from them the supply was delivered by gravitation. During the preceding twelve months a third well had been made, 90 feet away from the others and of similar depth. From 1861, and until the construction of the third boring, the water supplied by the company was held in high repute; but since that time, and prior to the epidemic, complaints had been made with regard to the water. These were due to an unavoidable turbidity and to interruptions in the process of softening. Apart from this turbidity and temporary hardness, there was no reason to believe that the water was objectionable; and considering the deep sources of the supply, it was by no means apparent how the water could have been the means of producing an extensive epidemic of typhoid fever. Dr. Thorne inquired carefully into the possibility of contamination of the supply *en route*, but with negative results. He next sought to discover whether any contamination had taken place in the reservoirs or in the mains. But these sources also were satisfactorily excluded. Many other points relating to the method of distribution of the water were inquired into, but none led to any explanation of the circumstances of the epidemic.

It was next suggested that cesspool drainage or soakage of surface filth might have existed around the company's wells. Certain cesspools were found in the vicinity,

but after careful examination were excluded as probable sources of contamination.

In the meantime facts were brought to light which led to an extension of the inquiry in another direction. It appeared that during the latter part of 1878 and the beginning of 1879, the company had constructed an adit from one of their old wells up to the new boring, which was then being sunk. This adit was in the chalk at a depth of 445 feet. It was 6 feet by 4 feet in section and 90 feet long. A number of men were employed in the work, some of them being in the wells below, others on the surface. It was ascertained that one of the men who left work some time in January was reputed to have been ill, though no inquiries had been made concerning him since he quitted the works. This man was sought out, and eventually the following facts were obtained:—

"J. K., aged thirty-two years, resided in Caterham, and was employed by the company as a laborer from October 25, 1878. The work assigned to him was that of 'loading-man,' he being employed in the adit below in attaching to a rope let down from above the buckets by which the excavated chalk was raised to the surface, and in again receiving those buckets when lowered full of bricks and cement required for the work in progress. From December 14 to December 29, J. K. was absent. When he returned he was in perfect health, but in about a week, that is, about January 5, 1879, he felt himself ailing. His symptoms, which, according to his statement, steadily increased, were at first loss of appetite, recurring attacks of shivering alternating with a feeling of heat, great pains in the limbs which he attributed to rheumatism, but which, instead of being confined to any of the joints, were described both by himself and by his wife as an 'aching all over,' and diarrhœa. As the symptoms became aggravated, he was so exhausted during his work and became so 'giddified' that he was more than once drawn to the surface, and immediately on his return home he was compelled to go to bed. More than once his wife noticed that he was 'light-headed' in his sleep. All this while the diarrhœa continued, the man making a great effort to remain at his work, because, as explained, he had had no employment between the 14th and the 29th of the previous month.

"With reference to this man's diarrhœa, it is necessary to make the following explanation: Both from his own statement, and from that of

others, it appears that all the men who worked in the adit were expected to make such preparation before descending the well that no occasion should exist for relieving themselves below; but should such necessity ever arise, and should there be at such a time any difficulty or delay in their being drawn to the surface, the buckets which were regularly being raised to the surface were to be used for that purpose. J. K. states that he strictly complied with these regulations before descending, but that, notwithstanding all his efforts, the purging under which he was laboring was such that he was compelled to evacuate whilst in the adit 'at least two or three times' during each shift, the shifts lasting apparently from eight to twelve hours each, according to circumstances. Indeed, as time went on, the man's diarrhœa must have been considerable, for besides the attacks which came on whilst in the adit, he almost invariably suffered from it before descending, immediately after ascending, and also at his own house. So matters continued until January 20, when work was again suspended for two days on account of a rise in the water level. But during the night of the 21st he was so much worse that he was unable to rise next morning. According to his wife's statement, he found he could not stand when he got up, and returning to his bed, suffered from 'shivering down the back, aching, and exhaustion'; and later on severe abdominal pain came on which compelled him to lie with his knees drawn up; he was also 'burning hot.' This pain was looked upon as 'cramp,' and was alleviated by linseed-meal poultices, which were applied by his wife. The more severe symptoms, including the diarrhœa, having subsided, he was two days afterward able to get up for a while, and from this time convalescence appears to have set in. No medical advice was sought, mainly, as he explained to me, owing to his straitened circumstances. When I saw him, on February the 8th, he had the aspect of a man who had recently suffered from some acute disease; he was still very weak, and it was obvious that he had greatly lost flesh."

Dr. Thorne and Dr. Jacob with extreme care searched further into the history of this case, with the following result, in Dr. Thorne's words:—

"I have now no hesitation in taking it as a fact, that a man ill of enteric [typhoid] fever from January 5 to the end of the month was occupied during the first fortnight of that period at work in the well of the Caterham Waterworks Company. The fact, it will be observed, is not inferred from any consequences of it, but simply from what was seen and heard of the particular individual.

"But now let us see what those consequences would have been. If

this man's stools could by any means have found their way into the water of the well in which he had been working, and being enteric fever stools could thus have led to the development of the poison of that disease in the well, the effect on the water consumers ought to have been noticed within from about ten to fifteen days after the date when the diarrhœa first came on. And this, in effect, is precisely what did take place, the epidemic having commenced on January 19 and 20 in Caterham and Red Hill, respectively. This remarkable concurrence of dates led to a more detailed inquiry as to the course of the man's diarrhœa whilst working in the adit. He admitted that the purging was very copious, in short, that it 'ran from' him; indeed, when at home, he was, because of the suddenness of its onset, unable to resort to the closet. He further admitted that, owing to his frequent use of the bucket whilst at work, complaints were made by his fellow-workmen on the surface; but he stoutly denied that he had ever been so pressed by necessity, or so influenced by those complaints, as to relieve himself in the adit without waiting for a bucket. But even accepting his denial, there were undoubted means by which his evacuations could have found their way into the water. According to his statement, the bucket was used as a closet when it was empty, when half full, and when full; he added, however, that when it was full he first took some of the chalk out and subsequently replaced it. During an earlier stage of my inquiry I had occasion to descend one of these wells, and I noticed that any article let down by a rope, by its oscillations to and fro, came into constant and somewhat violent contact with the walls of the wells, and on inquiry of J. K. whether the same did not take place with the bucket, he admitted not only that this was so, but that some of its contents frequently fell over a stage into the water below. On further inquiry, he added that some portions of his evacuations probably did so also. And he further stated that the looseness of his bowels was such that the bucket itself must almost of necessity have been stained with them. This bucket, which was merely emptied out above, then received, as already explained, materials which were used in the construction of the works below. Here, then, were the stools of an enteric fever patient, from about January 5 onwards, getting into the Caterham Company's water and distributed with that water to the district served by the company.

"Now we know from ample experience that enteric fever is produced, and produced with the maximum of certainty, when the specific evacuations of that disease are consumed by a population. Again, it is a matter of experience that where enteric fever has been conveyed through water, some fortnight has to elapse between the distribution of the water and the occurrence of the disease among the community served

by it. But a fortnight after January 5 to 19, *i.e.* from January 19 to February 2, the disease became widely spread throughout Caterham and Red Hill; the distribution of the fever being limited, as we have already seen, to houses supplied with the water of the Caterham Company. There can, I think, be no doubt that we have in the man J. K. the cause of the disease which followed."

A further study by Dr. Thorne made with similar care showed that wherever the Caterham water indubitably went, typhoid fever was also distributed. A part of this latter investigation was particularly interesting. The village of Warlingham, lying about three miles from the Caterham Company's Works, was supplied by that company with water, and yet had no typhoid fever. It appeared in the sequel, however, that in order to add to the Caterham Company's supply during certain portions of the time when the Caterham wells were undergoing alterations and furnishing a diminished supply, water had been pumped into the Caterham Company's mains by the Kenley Waterworks Company; namely, continuously every night after November 26, 1878, to January 3, 1879; resumed again from January 5 to 10, then discontinued until the nights of the 14th and 15th, finally ceasing on the morning of the 16th. This water was therefore pumped into the Caterham Company's mains for the period January 5 to 9, during which the distribution of infection must have commenced. The Kenley water was not, however, mixed directly with the Caterham water. It was pumped in at one particular point, and that point was the extreme farther end of the Warlingham branch of the system. Furthermore, the capacity of the main between Caterham and Warlingham, and of the branches of this main in Warlingham, was somewhat over 12,000 gallons. Accordingly, before the Kenley water could get to the Caterham Company's reservoirs, it had to fill the whole of the three-inch Warlingham main and its system of branches, besides one other larger main nearer to Caterham. It is therefore fair to suppose that the inhab-

itants of Warlingham rarely, if at all, and probably never, during this time, received any of the Caterham water. In the end Dr. Thorne was led to believe that the almost complete exemption of Warlingham — for only a single case appeared there during the epidemic period — was powerful support to his views in regard to the true source of this epidemic.

The total number of cases was 352, and the total number of deaths, 21, to the end of February. After that time only a few scattered cases occurred. The disease, as has been stated, was typical typhoid fever, the patients exhibiting the characteristic rose-spots, diarrhœa, etc. Most of the cases were of an exceptionally mild character, and the majority attacked were children. Amongst adults, women were more frequently attacked than men. The low fatality is noteworthy, and agrees with the theory of great dilution of the infectious material.

§ 8. — *An Epidemic of Typhoid Fever in Plymouth (Pennsylvania) traced to a Polluted Surface Water Supply*

One of the most instructive epidemics in the annals of sanitary science is the epidemic of typhoid fever which sprang from a polluted water supply in Plymouth, Penn., in the spring of 1885. Plymouth at that time was a mining town of about eight thousand inhabitants. It had grown up rapidly, and was not in good sanitary condition; but it was provided with an apparently excellent, though limited, public water supply derived from a mountain stream, traversing an almost uninhabited watershed. There were, in fact, on the watershed only two houses so placed as to be able to contaminate the supply. It would appear from the excellent report of Dr. L. H. Taylor,[1] of Wilkesbarre, from which the present account is drawn, that the inhabitants

[1] First Annual Report, State Board of Health and Vital Statistics of Pennsylvania, pp. 176-195. Harrisburg, Penn., 1886.

of one or both of these had nevertheless for some time, perhaps for years, been polluting the public supply of Plymouth with ordinary fæcal matters; but no harm was observed or even suspected until April, 1885, when, as was afterward discovered, the specific infection of typhoid fever was superadded to ordinary fæcal pollution. Thereupon, out of a population of about 8000 persons, 1104 contracted typhoid fever, and 114 died. The story may be briefly told.

"The first case belonging to this epidemic occurred on April 9, and from this time on the disease spread rapidly. During the week beginning April 12, from fifty to one hundred new cases appeared daily. and on one day it is said two hundred new cases were reported. . . Various theories were put forth, some declaring it [the epidemic] to be due to the filth of the town; some that it was due to drinking polluted well water; others, polluted river water; and still others that it was due to a peculiar condition of nature, by no means explainable.

"Among the various theories advanced, one of the first was that it was due to the accumulated filth of the town, which, being acted upon by the warm rays of the April sun, had suddenly become noxious, and the emanations, therefore, had caused the disease. This especially suited the 'typho-malarial' theorists. But although Plymouth was not an especially clean town, it was not, on the other hand, more filthy than other neighboring towns where the disease did not prevail, nor was it at this particular time in worse condition than in preceding years. . . .

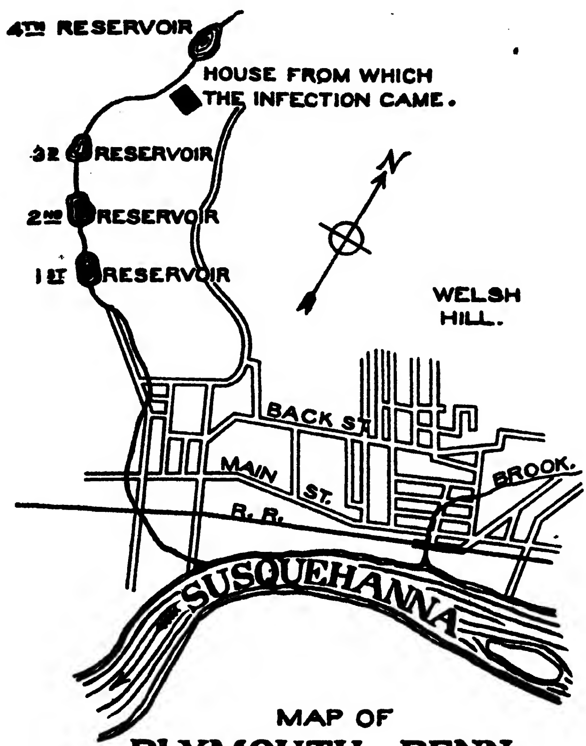
"All classes of people were attacked, the clean as well as the filthy, and all parts of the town affected, the highlands as well as the valley . . . and thoughtful minds naturally turned to the water supply as furnishing the true cause of the invasion."

In addition to certain wells and springs the inhabitants had access to one or both of two public water supplies. A small portion of the town received regularly water from the Susquehanna River, pumped by the Delaware and Hudson Coal Company, and those who used this water exclusively did not suffer from the disease. The greater portion, however, was supplied by the Plymouth Water Company, which in 1876 began supplying the town "with water of remarkable purity, from a neighboring mountain stream

which had its source in a beautiful sand spring some miles away." On the stream had been built, successively, four storage reservoirs: No. 1, the first, the lowest, and that serving as the distributing reservoir (see diagram), having a capacity of 300,000 gallons; No. 2, next above, a capacity of 1,700,000 gallons; No. 3, still higher, of 3,000,000 gallons; and finally, No. 4, highest of all, of 5,000,000 gallons. In spite of this storage capacity, however, the supply was at times insufficient, and was then supplemented by direct pumping from the Susquehanna River, a stream polluted, and at times infected, by the sewage of Wilkesbarre, a city of 30,000 inhabitants, lying on the same river only three miles above. "Water from the river was first pumped . . . in 1878, and occasionally in succeeding years, *e.g.* in 1881, 91 days; in 1882–1883, . . . 65 days; 1883–1884, 124 days; 1884 [additional], 118 days. This water, though objectionable, . . . has never been followed by any [reported] epidemic of typhoid fever."

In the spring of 1885 resort was again had to the river, which was used just before the epidemic appeared, viz. from March 20 to 26, 1885. Dr. Taylor was therefore obliged to consider very carefully the possibility that the source of the epidemic lay in the river water. He was able, nevertheless, by various independent lines of evidence, to show conclusively that the great epidemic, which began with a single case on April 9, and by the end of another week had risen to alarming proportions, could not possibly be attributed to the use of the sewage-polluted river water. It was easy to show that the milk supply and the well-water and spring-water supplies could not furnish adequate explanation of the epidemic, so that there remained only the mountain supply of water to be investigated.

"There remains but one possible cause for this most serious and deplorable outbreak, and that is contamination of the water supplying the company's reservoirs. A glance at the accompanying map will show the location of this stream and of the several reservoirs. Above the



MAP OF
PLYMOUTH, PENN.
IN 1885.

starting point of the water pipes there is but one house situated upon the banks of this stream, and one upon the banks of the fourth reservoir.

"In the house between the third and fourth reservoirs, situated almost immediately upon the stream, there lives a man who but recently has recovered from the effects of a severe attack of typhoid fever. This patient went to Philadelphia, December 24, 1884, and while there, he thinks, contracted the disease. Whether he did thus contract the disease in Philadelphia may, we think, admit of question. But it is nevertheless true that he returned to his home, January 2, 1885, and for many weeks was seriously ill with genuine typhoid fever. Early in March he was convalescent and was out of bed. A relapse occurred about the middle of March, and he was very sick on the 16th. On March 16 and 17 he had hemorrhages of the bowels of so severe a type that, on March 18, his life was despaired of, even by his physician.

"He, however, rallied, was quite ill for some time, but was convalescent in April, so that his physician discontinued his visits after April 12.

"During the course of his illness, his dejecta passed at night, without any attempt at disinfection, were thrown out upon the snow and frozen ground, toward and within a few feet of the edge of the high bank, which slopes precipitously down to the stream supplying the town with water.

"The nurse in charge states explicitly that in emptying the chambers at night she did not stand on the porch to throw out the contents, but stepped down some distance and threw them into the creek. If she stepped but a few feet away from the porch, she would empty the excreta within twenty-five or thirty feet of the edge of the stream.

"The dejecta passed during the day were emptied into a privy a little farther back, the contents of which lie almost upon the surface of the ground, and at the first thaw or rain they too would pass down the sloping bank and into the stream. These dejecta were thrown out from time to time until the accumulation no doubt equalled the daily passages from many such patients. They remained innoxious upon the snow and frozen ground until some time between March 25 and April 1, when they were washed into the stream and thence into the third reservoir.

"The house in question does not stand in a ravine nor in a protected spot, but in an open clearing, with land sloping toward the south, which clearing would naturally feel the effects of the sun's rays and part with its snow and accumulated filth sooner than the more protected regions which also drain into the stream, so without cavil the first water from the effects of the thaw to enter the third reservoir would be from the melted snow in the immediate vicinity of this house.

"The maximum temperature . . . was on March 26, 46.5° F.; March 27, 56°; March 28, 43°; March 29, 37°, increasing rapidly until April 4, when a temperature of 70° F. was reached.

"March 26, with a maximum temperature of 46.5° F., is the first day on which any considerable thaw could occur. Upon the evening of this day, the superintendent of the water company visited the reservoirs to ascertain whether it would be allowable to discontinue the pumping of river water. He found the first and second reservoirs almost entirely empty, while the third was filling rapidly, the short pipe which allows the water to discharge from the bottom of the third into the stream leading to the second reservoir being tightly frozen.

"He caused a fire to be built to melt the ice in this pipe, and then stopped the river pumps. The honest act of an honest man, and simply in the discharge of his duty and with kindliest intent. But of what a catastrophe was he the unconscious usher and hastener! The water, with its accumulated typhoid fever poison, was discharged from the bottom of the third reservoir, ran down to the second, on to the first, and was thence distributed to the town, in all probability between the 28th of March and the 4th or 5th of April.

"In considering the possibility of one patient poisoning more than a thousand in Plymouth, we must bear in mind all the attending circumstances: —

"1. The accumulation of weeks — which equalled the dejecta from many ordinary patients, and which lay for a time dormant upon the snow and frozen ground.

"2. The nearness to the stream. The house is so situated that all of the excreta were thrown within a few yards of its banks, and the conformation of the ground is such that its surface water could not possibly drain in any other direction.

"3. The unusually warm weather — which caused a sudden thaw and poured the surface water into the empty reservoir.

"4. The concentration of the poison in a small amount of water.

"5. The short distance to the town; and finally, the possible previous preparation of the soil for the reception of this seed, which sprang at once into vigorous growth and ripened for an abundant harvest of death.

"It would seem that the mere statement of facts, as found in the few preceding pages, is amply sufficient to explain the cause of this remarkable epidemic, and we need have no hesitation in declaring the pollution of the mountain stream, which supplies the reservoirs of the water company of Plymouth, to be the sole cause of the remarkable outbreak of typhoid fever in this borough.

"During the period of pumping from the Susquehanna, the water in that river was lower than it had been at any time for years, and the surface was frozen tight. The city of Wilkesbarre, containing thirty thousand inhabitants, delivers its sewage directly into the Susquehanna, the mouth of the lower sewer emptying only two miles above the Plymouth Pumping Station, while the current is very rapid between the two towns. The water is further contaminated by refuse water from five or six lines as well as by the garbage from the abattoirs at Wilkesbarre. Notwithstanding this unusually filthy condition of the Susquehanna River, it is beyond question entirely innocent of causing the epidemic. . . ."

Dr. Taylor's conclusions were confirmed in all essential particulars by other students of the epidemic, among whom may be mentioned Drs. Shakespeare and French of Philadelphia; Briggs of Buffalo; and Biggs, Taylor, Edson and others, of New York. The first to suggest publicly the pollution of the mountain supply as the probable cause of the epidemic was Dr. R. Davis (in a Wilkesbarre newspaper published on April 29).

We may readily agree with Dr. Taylor in his conclusions: —

"It is safe to say that this was one of the most remarkable epidemics in the history of typhoid fever, and it teaches us some important lessons, at fearful cost. One is, that in any case of typhoid fever, no matter how mild, nor how far removed from the haunts of men, the greatest possible care should be exercised in thoroughly disinfecting the poisonous stools. The origin of all this sorrow and desolation occurred miles away, on the mountain side, far removed from the populous town, and in a solitary house situated upon the bank of a swift-running stream. The attending physician did not know that this stream supplied the reservoirs with drinking water. Here, if any place, it might seem excusable to take less than ordinary precautions; but the sequel shows that in every case the most rigid attention to detail in destroying these poisonous germs should be enjoined upon nurses and others in charge of typhoid fever patients, while the history of this epidemic will but add another to the list of such histories which should serve to impress medical men, at least, with the great necessity for perfect cleanliness — a lesson which mankind at large is slow to learn.

"Another lesson taught by this history comes more nearly home to us all. The water-companies throughout our land should be taught

that they must furnish us the water for which we pay, from the very best source which the country affords. Not only should they avoid the use of river water contaminated by sewage, but they should be compelled to remove from the banks of their streams and reservoirs not only all probable, but all possible sources of pollution."

Dr. M. S. French made an interesting estimate of the financial waste or loss involved in the Plymouth epidemic, and his paper, which follows that of Dr. Taylor (pp. 196–217, *l. c.*), contains also a complete and impressive list by name of those attacked with typhoid fever. Dr. French estimates the cost of the sickness — "expenses incurred by the epidemic" — at $67,100.17, of which $8,000 were spent in maintaining a temporary hospital.

"Of those who were ill with the disease and recovered, the loss of earnings during their illness was found to be $30,020.08. Thus the total cost of the epidemic is reckoned at $97,120.25. By the 114 deaths, a monthly earning of $1,534.96 ceased, showing a loss of $18,419.52 per year in incomes."

Dr. French does not, as he might have done, capitalize this latter sum, and add the result to the gross loss; if he had done so, he might have concluded that the total cost of this disastrous epidemic was more than half a million of dollars. It will be observed that the fatality (114 deaths in 1104 cases) was much higher than in the Caterham epidemic (21 deaths in 352 cases), or 10.3 per cent against 5.9 per cent, and that this corresponds well with the probable relative concentration of the infectious material in the two epidemics.

§ 9. — *Typhoid Fever in Lowell, Lawrence and Other Cities on the Merrimac River*

In the valley of the Merrimac River, which is a large, swift stream draining a considerable portion of southern New Hampshire and northern Massachusetts, are situated a number of cities and towns of which the history in respect to typhoid fever is interesting and instructive. Situated in the same valley, under closely similar climatic conditions, they are also, for the most part, manufacturing towns or cities, and have populations especially favorable for purposes of sanitary comparison. Lowell, Lawrence and Manchester are devoted chiefly to textile industries, and nearly the same might be said of Nashua and Concord, while Haverhill is what is called a "shoe" town, and Newburyport, while possessing some textile industries, is more diversified in this respect.

In connection with his duties as biologist to the State Board of Health in Massachusetts, and especially with his work at the Lawrence Experiment Station of that Board, the author was already somewhat familiar with the sanitary history of the cities and towns situated in the Merrimac Valley, when, in December, 1890, a serious epidemic of typhoid fever having appeared in the city of Lowell, lying only nine miles above Lawrence, he was instructed by the Board to make a thorough investigation. At almost the same time he was also invited by the Water Commissioners of Lowell to conduct a similar inquiry on their behalf. Accordingly, clothed with ample authority and provided with every opportunity, he set to work.

The population and death-rates from typhoid fever in the principal cities of the Merrimac for the two years preceding the outbreak of the great epidemic of 1890–1891 are shown in the following tables: —

TYPHOID FEVER IN THE PRINCIPAL CITIES ON THE MERRIMAC RIVER

DEATHS PER 100,000 INHABITANTS (POPULATION FROM UNITED STATES CENSUS OF 1890)

1888-1889

	April	May	June	July	August	September	October	November	December	January	February	March	Totals for the Twelve Months
Concord, N. H.	.0	.0	.0	.0	5.9	17.6	17.6	17.6	11.8	.0	.0	.0	70.5
Manchester, N. H.	.0	2.3	4.6	.0	.0	4.6	.0	6.9	6.9	2.3	.0	2.3	29.9
Nashua, N. H.	5.3	.0	.0	.0	.0	15.9	31.8	5.3	10.6	.0	.0	.0	68.9
Lowell, Mass.	10.4	7.8	3.9	3.9	3.9	10.4	6.5	9.2	9.2	5.3	6.6	9.2	86.3
Lawrence, Mass.	11.2	9.0	11.2	2.2	9.0	.0	17.9	13.4	13.4	4.4	15.6	17.9	125.2
Haverhill, Mass.	.0	.0	3.8	.0	3.8	3.8	3.8	.0	.0	3.8	3.8	.0	22.8
Newburyport, Mass.	.0	.0	.0	.0	.0	.0	.0	.0	7.2	.0	7.2	.0	14.4

1889-1890

	April	May	June	July	August	September	October	November	December	January	February	March	Totals for the Twelve Months
Concord, N. H.	5.9	5.9	.0	5.9	.0	.0	11.8	.0	.0	.0	.0	.0	29.5
Manchester, N. H.	2.3	.0	2.3	2.3	7.0	4.7	4.7	9.3	4.7	4.5	.0	.0	41.8
Nashua, N. H.	.0	.0	.0	.0	.0	.0	5.3	10.7	5.3	5.3	10.6	5.3	42.5
Lowell, Mass.	9.2	6.6	4.0	1.3	6.6	9.2	4.0	11.9	11.9	6.4	7.7	5.1	83.9
Lawrence, Mass.	8.9	8.9	11.2	4.4	6.7	15.6	8.9	6.7	13.4	15.6	13.4	4.4	118.1
Haverhill, Mass.	3.8	.0	.0	3.8	3.8	.0	7.5	.0	3.8	3.8	3.8	.0	30.3
Newburyport, Mass.	.0	7.2	.0	14.4	0	.0	.0	.0	.0	7.2	.0	.0	28.8

The death-rates for the epidemic years 1890–1891 are shown in the following table: —

TYPHOID FEVER IN THE PRINCIPAL CITIES ON THE MERRIMAC RIVER

DEATHS PER 100,000 INHABITANTS (POPULATION FROM UNITED STATES CENSUS OF 1890)

1890-1891

	April	May	June	July	August	September	October	November	December	January	February	March	Totals for the Twelve Months
Concord, N. H.	5.9	11.8	.0	.0	11.8	17.6	.0	.0	.0	.0	.0	5.9	53.0
Manchester, N. H.	.0	2.3	.0	2.3	4.6	6.9	.0	6.9	11.4	4.6	4.6	.0	43.6
Nashua, N. H.	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.3	.0	5.3
Lowell, Mass.	7.8	10.4	11.6	7.8	7.8	12.9	12.9	36.3	32.3	24.6	18.1	12.9	195.4
Lawrence, Mass.	11.2	.0	11.2	2.2	2.2	4.5	11.2	15.6	42.6	47.0	26.9	13.4	187.0
Haverhill, Mass.	7.5	3.8	.0	7.5	.0	11.3	.0	3.8	.0	.0	.0	.0	33.9
Newburyport, Mass.	.0	.0	7.2	.0	.0	14.4	21.6	.0	7.2	7.2	.0	.0	57.6

The death-rates for the same cities for the two years next after the great epidemic of 1890–1891 are shown in the following tables: —

TYPHOID FEVER IN THE PRINCIPAL CITIES ON THE MERRIMAC RIVER

DEATHS PER 100,000 INHABITANTS (POPULATION FROM UNITED STATES CENSUS OF 1890)

1891-1892

	April	May	June	July	August	September	October	November	December	January	February	March	Totals for the Twelve Months
Concord, N. H.	5.9	.0	.0	.0	17.6	.0	5.9	.0	.0	.0	.0	.0	29.4
Manchester, N. H.	2.3	.0	2.3	.0	.0	.0	.0	.0	.0	4.6	.0	2.3	11.5
Nashua, N. H.	.0	.0	.0	.0	15.8	15.8	10.6	31.7	5.3	5.3	5.3	.0	89.8
Lowell, Mass.	7.8	5.2	1.3	5.2	3.9	3.9	9.1	3.9	2.6	16.8	10.4	11.6	81.7
Lawrence, Mass.	6.7	4.5	2.2	2.2	2.2	11.2	6.7	9.0	2.2	11.2	15.6	17.9	91.6
Haverhill, Mass.	7.5	.0	.0	.0	3.8	.0	.0	3.8	3.8	7.5	3.8	.0	30.2
Newburyport, Mass.	.0	7.2	7.2	.0	.0	.0	7.2	.0	7.2	.0	.0	.0	28.8

1892–1893

	April	May	June	July	August	September	October	November	December	January	February	March	Totals for the Twelve Months
Concord, N. H.	.0	5.9	.0	.0	.0	.0	.0	.0	5.9	.0	.0	.0	11.8
Manchester, N. H. . .	2.3	.0	4.6	6.9	.0	2.3	.0	.0	2.3	2.3	.0	.0	20.7
Nashua, N. H.	.0	.0	.0	.0	.0	5.3	.0	15.9	5.3	.0	5.3	.0	31.8
Lowell, Mass.	5.2	9.1	2.6	5.2	5.2	9.1	5.2	3.9	12.9	12.9	9.1	5.2	85.6
Lawrence, Mass. . . .	6.7	2.2	4.5	9.0	4.5	.0	6.7	9.0	20.1	6.7	26.8	17.9	114.1
Haverhill, Mass. . . .	3.8	.0	3.8	3.8	.0	7.5	.0	3.8	22.5	.0	15.0	3.8	64.0
Newburyport, Mass. . .	.0	14.4	.0	.0	.0	.0	.0	.0	7.2	21.6	.0	7.2	50.4

The death-rates from typhoid fever for twelve-month periods in the principal cities on the Merrimac River, for five years in succession, are shown on the following table: —

DEATH-RATES FROM TYPHOID FEVER, BY PERIODS OF TWELVE MONTHS, IN THE PRINCIPAL CITIES ON THE MERRIMAC RIVER, FOR THE FIVE YEARS, APRIL 1, 1888, TO MARCH 31, 1893.

DEATHS PER 100,000 INHABITANTS (POPULATION FROM UNITED STATES CENSUS OF 1890)

	From Apr., 1888, to Mar., 1889	From Apr., 1889, to Mar., 1890	From Apr., 1890, to Mar., 1891	From Apr., 1891, to Mar., 1892	From Apr., 1892, to Mar., 1893	Average Apr., 1888, to Mar., 1893
Concord, N. H.	70.5	29.5	53.0	29.4	11.8	38.8
Manchester, N. H. . .	29.9	41.8	43.6	11.5	20.7	29.5
Nashua, N. H. . . .	68.9	42.5	5.3	89.8	31.8	47.7
Lowell, Mass. . . .	86.3	83.9	195.4	81.7	85.6	106.61 [1]
Lawrence, Mass. . .	125.2	118.1	187.0	91.6	114.1	127.2. [1]
Haverhill, Mass. . .	22.8	30.3	33.9	30.2	64.0	46.3
Newburyport, Mass.	14.4	28.8	57.6	28.8	50.4	36.0

A very brief consideration of the facts laid down in this table reveals certain striking phenomena. In the first place, it is evident that none of these cities was free from

[1] Excluding 1890–1891 (the period of the great epidemic), the average for the other four years is 84.4 for Lowell, and for Lawrence, 112.25.

typhoid fever, at least for any considerable length of time. In the second place, on the whole (as seen from the last column of the last table), the average amount of typhoid fever in all the cities excepting Lowell and Lawrence was very much the same. All the tables, however, display a marked excess of typhoid fever in Lowell and Lawrence over that in the other cities, and in the year of the great epidemic (1890–1891) this excess is especially notable. Those who desire to follow the facts in detail are referred to the original reports of the author.[1] The main points, however, will be touched upon here.

It has already been stated that these cities are closely similar in climate and pursuits, and the same thing may be said of them in every other important respect excepting one, namely, their water supply, which in the cases of Lowell and Lawrence only, during these years and for some years preceding, had been derived directly from the Merrimac River, a sewage-polluted stream, without any attempt whatever at purification. The water supplies of Concord, Nashua and Haverhill and, during most of the time, of Newburyport, on the other hand, were derived from other sources, as a rule entirely unobjectionable, and in some cases, as for example that of Nashua, remarkably pure.

When in the autumn of 1890 the great epidemic of typhoid fever broke out in Lowell, one even more severe soon after appeared in Lawrence. The former was traced to an unusual infection of the Merrimac River by cases of typhoid fever in a suburb of Lowell, through a little feeder of the river known as Stony Brook, which entered it only three miles above the intake of the waterworks. That in

[1] On recent epidemics of typhoid fever in the cities of Lowell and Lawrence due to infected water supply, with observations on typhoid fever in other cities and towns of the Merrimac valley, especially Newburyport. Illustrated by maps, photographs, etc. Twenty-fourth Report (for 1892) State Board of Health of Massachusetts, pp. 667–704. Boston, 1893.

the latter was plainly due to the same cause, to which was added the pollution and infection of the river by the sewage of Lowell (at that time a city of eighty-five thousand inhabitants), the sewers of which emptied into the river only nine miles above the intake of the Lawrence waterworks. There were all together probably upward of fifteen hundred cases of the disease in the two cities, as a result of this infection of the public water supplies.

A number of interesting facts were developed as the result of careful studies made of this epidemic by Mr. Hiram F. Mills,[1] Mr. George V. McLauthlin, and the author. It was discovered, for example, by Mr. Mills, that Lowell and Lawrence had long suffered annually from two autumn increments of typhoid fever, instead of one as is customary in most places, and that the first was contemporaneous with that in other cities and towns of the state, while the second arrived considerably later. The latter was evidently due to the fact that the water supplies of the two cities had become infected as a result of the usual autumn increment of the disease in the cities and towns on the river above, so that the second increment was a crop of which the first was the seed.

It was discovered by the author that the problem of typhoid fever in these cities was much complicated by the prevailing custom in both of distributing in the numerous mills and factories water so placed as to be accessible for drinking purposes (and in fact much used by the operatives of whom the population is largely com-

[1] To Mr. Mills, the distinguished hydraulic engineer, whose paper largely devoted to this epidemic ("Typhoid Fever in its Relation to Water Supplies," Twenty-second Annual Report State Board of Health of Massachusetts, for 1890, pp. 525–543) is of great interest and value, sanitary science is under deep obligations for many years of able, disinterested, volunteer service. In Mr. McLauthlin, whose early death cut short a career of unusually brilliant promise, sanitary science lost an enthusiastic, devoted and tireless worker, whose labors in epidemiology for the State Board of Health of Massachusetts deserve remembrance.

posed), which was derived directly and unpurified from little branches of the river (called *canals*) used for power, washing, etc., by the mills, which were in some cases polluted within the city itself by excreta from other mills, the public hospital, privies, etc.

The Lowell and Lawrence epidemic of 1890–1891, on the Merrimac River, also threw great light on the interpretations properly to be put upon chemical water analyses, and on the theory of the self-purification of streams; for the chlorine present in the river at Lowell was no greater than that often observed in good drinking water (owing to the rising of the river far from the sea, the source of the chlorine in the natural waters of New England), although it was known to have received *en route* vast quantities of sewage from the towns and cities on its banks; and while it had seemingly been purified by its long journey, it was plain from the vital statistics of the two cities — and especially those of Lawrence as compared with Lowell — that purification had been only too incomplete. Thanks to the careful investigations of Professor (now President) Drown, chemist of the State Board of Health of Massachusetts, the former error was easily detected by a determination of the "normal chlorine" of the river at its source. The latter error (the seemingly trustworthy "self-purification") was readily accounted for by a careful consideration of the natural and heavy contribution to the river of well-filtered ground water, which serves to dilute, and possibly to damage, but not necessarily to destroy, microbic life.

§ 10. — *Pollution* versus *Infection*

A study of the facts given in the preceding paragraph proves what is now well known, namely, that the use of water polluted with ordinary sewage free from specific infection is not necessarily followed by harmful consequences. The great sewers of the cities on the Merrimac

River above Lowell poured their sewage into the river constantly, and yet at times there was little or no typhoid fever in Lowell. After the usual autumn infection of the river, however, typhoid fever abounded in Lowell (and later in Lawrence); and when in 1890 an extensive and unusual infection occurred on a near feeder of the Merrimac, which had for many years poured in its sewage without marked effect, a great epidemic quickly broke out in both cities. There is every reason to believe that in the case of wells, springs, and other sources of water supply, the same law holds. Mere pollution with uninfected sewage, or with thoroughly purified sewage, may do little or no harm. Something more than ordinary pollution is required; there must be infection in the sewage and the presence of active, virulent and specific germs of disease. The same thing is illustrated by the case next to be considered.

§ 11. — *The Case of Newburyport, Mass.*

In January, 1893, an outbreak of typhoid fever in the city of Newburyport, at the mouth of the Merrimac, furnished a striking and instructive demonstration of that difference which exists, and is too often forgotten, between general "pollution" and specific "infection."

The city of Newburyport had for many years derived its drinking water from large springs of an unobjectionable character, and typhoid fever had been of rare occurrence when suddenly, in January, 1893, an unusual number of cases of typhoid fever broke out almost simultaneously, and an investigation of them was made by the author. It soon appeared that there were in all about thirty cases, and on inquiry it proved that, as the springs had yielded an insufficient supply of water, a connection had been made with an intake pipe leading directly from the Merrimac River, through which the crude river water had been pumped into the pipes. It was also naively stated, by way of defence,

that this water could not have caused the typhoid fever "because the same thing had been going on since August." Assuming this to be true, as appeared to be the case, it was an extremely interesting fact, because the health records of the numerous cities and towns pouring sewage into the river above Newburyport showed very little typhoid fever in any of them in that year until the December just previous, at which time Lowell once more suffered from a small epidemic of typhoid fever, which seems to have borne its natural fruit in both Lawrence and Newburyport. In other words, as long as the people of Newburyport drank the waters of the Merrimac merely polluted with ordinary sewage, no typhoid fever (or other infectious disease) appeared; but when the specific bowel discharges of typhoid fever were added to the sewage, this disease speedily broke out. (See report by the author on the Newburyport outbreak, Twenty-fourth Annual Report State Board of Health of Massachusetts (for 1892), pp. 701–704.)

From this and many other similar cases we have reason to believe that sewage-polluted water is ordinarily only a vehicle, and not usually in itself a source, of infectious disease.

§ 12. — *An Epidemic of Asiatic Cholera in Hamburg, Germany, traced to an Infected Public Water Supply*

The great epidemic of Asiatic cholera which occurred in Hamburg in 1892 was traced to an infection of the public water supply, probably due to the excrements of certain emigrants detained on ships in the Elbe while *en route* to America, and suffering from the disease in question. The water supply of Hamburg was at that time derived directly from the Elbe, and pumped, without purification of any kind, for the immediate use of the citizens. A neighboring suburb (Wandsbeck) and the city of Altona which forms virtually a part of Hamburg, remained almost entirely free from the disease. The former had an excellent water sup-

ply not drawn from the river; the latter drew its water supply from the river, and from a point where it contained more sewage than did the Hamburg water, but with this difference: — the Altona water supply was purified by filtration before it was delivered to the consumers. Since the epidemic, Hamburg has also introduced excellent filters, with most satisfactory results.

§ 13. — *An Epidemic of Typhoid Fever in New Haven, Conn., due to an Infected Surface Water Supply*

In the spring of 1901, typhoid fever appeared in excess in one portion of the city of New Haven, Conn., which was served by a water supply distinct from those supplies serving the remainder of the city. In all about 450 cases appeared within one month. Investigation showed that the outbreak was, in kind, not unlike that in Plymouth, Penn. (described above). The excrements of typhoid fever patients in a single house had found their way during heavy rains into a reservoir, which had previously been drawn low, so that the infection was carried quickly, and while comparatively fresh, to the consumers of the water, with disastrous results.

§ 14. — *Diseases Other than Typhoid Fever and Asiatic Cholera traced to Polluted Drinking Waters*

It is an interesting and very important question whether or not diseases, other than those already described, are capable of transmission by drinking water, and we are at present unable to answer the question satisfactorily. It is easy to see that much must depend on the conditions surrounding any particular case. For example, cholera infantum, diphtheria and measles are seldom, if ever, charged to polluted water supplies, and yet there is very little doubt that if the stay in the water of their germs should be short enough, the germs would survive and do their character-

istic damage. The truth appears to be that water is a much less favorable vehicle for some germs — such as those of diphtheria — than for others — such as those of typhoid fever; but in the present state of our ignorance it would be very rash to conclude that any particular germs may not, under favorable circumstances, be conveyed by drinking water acting as a vehicle.

§ 15. — *Dysentery and Diarrhœa*

In the case of dysentery and diarrhœa, there is no doubt whatever that drinking water may be, and often is, their ready vehicle. In almost all cases in which a pure water supply has been substituted for one impure, a marked diminution can be shown in the deaths attributed to these disorders.[1]

Previous to the improvement of the water supply of Burlington, Vt., in 1894, dysentery, and especially diarrhœa, were relatively prominent among the assigned causes of mortality; but since that time they have been insignificant. The case of Burlington,[2] in respect to diarrhœa, is peculiarly instructive. References to the local sanitary conditions of that city will be found on pp. 132, 234. In this connection it will suffice to state that in the early sanitary history of that city, when the water supply was drawn without purification from a point on the shore of Lake Champlain, relatively near the place where the principal sewer emptied into the same lake, typhoid fever and diarrhœa both prevailed, after a time, to an alarming degree. When, later (in 1885), the main sewer outfall was removed to a greater distance, typhoid fever diminished,

[1] See, for example, Dr. Buchanan's classical report, Ninth Report Medical Officer of the Privy Council, p. 16. London, 1867.

[2] See, on this subject, the author's paper, "On the Sanitary Condition, Past and Present, of the Water Supply of Burlington, Vt." *Journal, New England Waterworks Association*, Vol. X, No. 3, pp. 167–183.

but diarrhœa remained very prevalent. When, still later, in 1894, the sewage outfall and the water intake were still further separated, — the water intake having been carried out some three miles into "the broad lake," — endemic diarrhœa also disappeared.

§ 16. — *Concluding Remarks on Drinking Water as a Vehicle of Disease*

Space forbids extended treatment in this connection of many minor principles which have been worked out along the line of the epidemiology of diseases conveyed by water. A few of these may, however, be set down. One is that *the intensity of the epidemic appears to depend largely on the amount and the freshness of the infection.* That it depends on the amount is clear from the fact that the size of the epidemics in Lawrence followed obviously the size of the corresponding serious outbreaks in Lowell. That it depends on the freshness of the infection is shown, for example, by the tremendous effect upon Lowell of a small but near infection, while the same city had annually been exposed, without much doubt, especially in the autumn, to more extensive, but at the same time more remote, infection. The same thing is shown by the experience of Chicago. So long as water was derived from the two-mile crib, comparatively little typhoid fever developed; but when, in 1891, water was drawn so that more and fresher germs were received, an epidemic of the most serious and threatening character appeared.[1]

Another interesting series of facts appears when we consider the local conditions on the Merrimac above Lowell. Inasmuch as the river is very low in summer, so that for weeks at a time it is wholly diverted into the canals at Lowell and Lawrence to be used for power in the mills,

[1] Sedgwick and Hazen, "Typhoid Fever in Chicago." *Engineering News*, New York, April, 1892.

and inasmuch, further, as the sewers of the cities above these are constantly pouring their sewage into the river, it follows as a matter of course that at such times the amount of sewage in the river is relatively greater than at other times. It might, therefore, reasonably be supposed that a sewage-borne disease, such as typhoid fever, ought to be more abundant among those using the water at such times. It would also be expected that the bacteria which swarm so abundantly in sewage must be abnormally numerous in the river water at a time when sewage forms so large an element in its composition.

The facts, however, are precisely the reverse of what might at first sight have been reasonably expected. Typhoid fever was comparatively rare among users of the Merrimac when the river was "low" and concentrated, and frequent when the river was "high" and the sewage dilute. Bacteria were also few, comparatively. On looking for the explanation of these facts it was found in the local conditions. It appears that when the river is "low," although the sewage which it contains forms a larger proportion of its whole volume than at other times, yet the river then becomes a series of comparatively quiet mill-ponds, fed largely by the purest water which ever enters the river, namely, well-filtered ground water nearly free from bacteria. Purified partly by dilution with this purer ground-water, and partly by the intense and long light of summer days, by sedimentation in the relatively slow and quiet stream, and probably also by the action of larger micro-organisms such as algæ and infusoria, and even by higher plants such as *Anacharis* or *Vallisneria*, it finally comes to pass that the summer flowage is actually safer to drink than the impetuous freshets of the spring or autumn, which, though largely composed of rain water, in their violence corrode the surface of the earth, and bear swiftly to the consumer of the river water not only the foul washings of the surface soil, but also, with small opportunity for purifi-

cation, the fresh sewage of even remote cities and towns.[1] Hence the paradox, that when river water is freshest, it may be least safe; and when richest in sewage, it is not necessarily most dangerous.

The student of sanitary science is strongly advised to study in the most minute detail and, if possible, under a master in epidemiology, at least one epidemic of typhoid fever. Such epidemiological work is to the sanitarian what careful laboratory work is to the chemist, the physicist or the biologist.

[1] For an interesting and instructive example of the efficiency of relatively small and remote pollutions, see a report by the author on "The Sources of Typhoid Fever in Pittsburgh." Report of the Filtration Commission of the City of Pittsburgh, Penn. Pittsburgh, 1899.

CHAPTER IX

ON THE ESTABLISHMENT AND CONSERVATION OF PURITY IN PUBLIC WATER SUPPLIES[1]

"There is no river in the United Kingdom long enough to secure the oxidation and destruction of any sewage which may be discharged into it, even at its source." *Rivers Pollution Commission of 1868, Sixth Report*, p. 427. London, 1874.

"The public is hitherto very imperfectly protected against certain extreme dangers which the malfeasance of a water company, supplying perhaps half a million of customers, may suddenly bring upon great masses of population. Its colossal power of life and death is something for which till recently there has been no precedent in the history of the world; and such a power, in whatever hands it is rested, ought most sedulously to be guarded against abuse."—SIR JOHN SIMON, *Ninth Report of the Medical Officer to the Privy Council*, p. 28. London, 1867.

§ 1.—*Public Supplies as Public Dangers*

A PUBLIC supply is a public danger, and for two reasons: first, because it affects large numbers of people; and, second, because it is beyond their direct supervision and control. Along with the substitution of the convenience of public, for the inconvenience of private, supplies of gas, water, milk and transportation, goes inevitably the surrender of the privilege of private supervision and superintendence. This is one of the obvious disadvantages of urban life everywhere, and especially of life in great cities. The social unit —the family—can as a rule no longer use its own well, its own cow, its own carriage. It must depend as a rule upon

[1] Originally prepared by the author as the "Middleton Goldsmith" lecture of the New York Pathological Society, and read by him before the Society, March 15, 1898.

the public water supply, the public gas supply, the public milk supply, the public vehicle. These, of course, are often cheaper and more convenient, but, unhappily, often also more dangerous.

On the other hand, it is easy to see that public supplies may easily be made public safeguards. All that is necessary is to substitute for private supervision and private control such expert and scientific superintendence as the danger involved demands, and, so far as public supplies are concerned, a condition of the whole may often be obtained far superior to any within the reach of a single member or family of the community. It cannot, therefore, be too soon or too plainly understood that common sense, as well as science, absolutely requires from great cities the most expert public supervision attainable, in place of private supervision surrendered. This surrender, indeed, is not unconditional. If public service cannot or does not secure or provide such adequate and expert supervision, there will be a return to the more primitive state. Intelligent families will prefer country to urban life, and private to public supervision. The rapid growth of suburban populations, sometimes at the expense of the more urban, may be already, in part at least, due to the lack of such adequate supervision in great cities.

The most important public supplies of cities are food, drink and air. Of these the water supply is easily of the first importance to the sanitarian, for the reason that the air supply is as yet beyond his control, while the food supply, with a few exceptions, such as milk, raw oysters and certain fruits and vegetables, is purified by cookery before it is swallowed. Water, on the other hand, is swallowed raw, often (relatively speaking) in very large quantities, and it is now universally admitted that impure drinking water is a ready vehicle of disease.

It is one of the immense advantages of the zymotoxic theory of infectious disease that it has made easy of com-

prehension the precise method of conveyance of disease germs. At the same time it is no less valuable in other directions, since it makes it possible, at least for experts, to understand why some diseases are, and some are not, readily conveyed by water; how, precisely, impurity arises; how impurity may be avoided or overcome, and purity established; and finally, how purity, having been once established, may be effectually or ineffectually conserved. When we consider the enormous quantities of water required by large cities, most of which is not used for drinking, but all of which must be fit to drink,[1] we may readily appreciate the importance of the subject with which this lecture deals.

§ 2. — *The Atmosphere as the Source of Water Supply*

The ultimate source of all water supply, public or private, is the atmosphere, in which the vapor of water (derived from land or sea) is condensed and precipitated as rain, snow, dew or fog. Theoretically, every rain-drop must form about some material particle, and the only particles of this kind in the atmosphere are particles of dust. Dust particles are frequently largely composed of the bodies of micro-organisms, and hence it follows that at the very instant of its birth the rain-drop may enclose one or many micro-organisms. On the other hand, such bacterial bodies may not be alive, but dead; and dust consists of many other things than micro-organisms, bits of inorganic matter and organic, though unorganized, particles, so that only a few rain-drops, probably, can be conceived of as including micro-organisms, still less living micro-organisms, at the start. Again, it must not be forgotten that even if we assume the presence of some living micro-organisms in

[1] In the United States it has not usually been considered advisable to install two systems of water supply, one potable and one non-potable. This is done, however, in some places, *e.g.* in Paris. See on this subject Special Report, Mass. State Board of Health, upon a Metropolitan Water Supply, p. 217. Boston, 1895.

rain-drops, these are doubtless, with the rarest exceptions, saphrophytic and not pathogenic. Our present knowledge of the behavior of pathogenic germs in the air is very limited, and this is particularly the case with those diseases, such as typhoid fever and Asiatic cholera, which are oftenest water-borne. Granting, however, the possibility of their presence in air, and the possible concurrence of soluble organic particles, it is obvious that a drop of such naturally distilled water may become polluted and even infected from its very birth. As it falls into the lower layers of the atmosphere, richer in dust, the chance of such pollution must necessarily increase *pari passu.* The *possibility* of such atmospheric contamination of water, and even its infection, must never be forgotten, but yet cannot be regarded, in the present state of our knowledge, except in very rare and unusual cases, as important.

§ 3. — *The Pollution of Rain-water and Snow by Dust*

The phenomena afforded by snow deserve especial, though brief, mention in this connection. A snowflake, especially if moist, appears to be a kind of filter through which a relatively large amount of air passes as the snowflake falls; and this peculiarity of structure doubtless explains the fact that snow, particularly that first to fall, is often really dirty and rich in micro-organisms; while, at the same time, the atmosphere after a prolonged snowfall is bacterially, as well as to the senses, noticeably purified. It follows as a matter of course that melted snow or snow water — and, we may add, snow ice — is far from pure; and that the water derived from melted snow in periods of "thaw" is not, as it might be supposed to be, particularly pure. On the contrary, the author observed on one occasion, when a sudden thaw had poured vast quantities of such water into the Merrimac River, the largest number of bacteria he ever discovered in the city water of Lowell,

viz., 33,000 per cubic centimetre — a number far in excess of that observed when the spring freshets had polluted the river, or in summer, when the proportion of sewage to other water in the river is highest.

If, however, proof were needed that typhoid fever and other diarrhœal diseases can be conveyed otherwise than by water supplies drawn through or over the earth, it would be enough to mention those places, such as Bermuda, where water is obtained for drinking only from cisterns or cemented basins on the hills, in which rain-water only is collected, and where, nevertheless, typhoid fever is by no means unknown either among the troops or the citizens. It hardly needs to be added that such fever is probably not attributable to drinking water.

§ 4.—*Influence of the Earth upon the Purity of Rain-water*

Once the rain-drop, alone or combined with others, touches the surface of the earth or its appurtenances — such as rocks, trees, roofs, fences, haystacks, animals — it meets, almost immediately, abundant dust or dirt, including matters organic and inorganic, soluble and insoluble, living and lifeless. As it rolls over the dusty rock alone, or with others forming a trickling stream, it naturally dissolves some substances and sweeps on others mechanically — its departure from purity increasing as it proceeds. If it wears away the soil, enough of the latter may be carried along to make it discolored or even muddy, no chemical analysis of such water being needed to show its pollution, while bacterially it is charged with thousands of micro-organisms in every cubic centimetre. This is its horizontal or surface-displacement history. If, on the contrary, the rain-drop falls upon porous, absorbent earth, not already water-logged, it will sink by gravity, possibly also by capillarity, or by the push of other particles from behind, down into the spongy earth. This will be a vertical displace-

ment; and here, also, it will as a rule come into contact with matters organic and inorganic, soluble and insoluble, living and lifeless. Whether its alighting place be sand or soil, it will usually find the porous earthy particles mantled with bacterial jelly, dead or alive, wet or dry. And immediately actions and reactions, physical and chemical, will begin, and continue until a new condition has arisen. Water, that thus on touching the earth takes the vertical direction, is commonly called "ground" water; while that which quickly moves off more or less horizontally is called "surface" water. Both, it will be observed, are comparatively impure when they arrive on the earth; that is to say, they consist of pure water holding in solution and suspension certain organic and inorganic, living and lifeless, substances derived from the atmosphere.

This is perhaps the best place to remark that the terms "pure" and "impure" are relative only. We have thus far used these terms in the chemical sense, yet, in the popular sense, rain-water is remarkably pure. We may allow the popular meaning and still keep in mind the fact that rain-water, from the chemical and bacterial point of view, is of relative purity only. From this point onward, it will be convenient if we consider separately the two great classes of natural waters, namely, "ground" waters and "surface" waters.

§ 5.—*Rain-water and the Living Earth. Ground Waters and their Pollution and Purification*

Rain-water on entering porous earth (either sand or soil open or close in texture) is at once brought under new conditions and into close contact with swarming bacterial life. The earth is the home of the bacteria. They are found in the air, but only because they have been lifted into it by winds, in the form of dried earth or dust. They are found in water,—in streams, lakes and the sea,—but seldom in density of population at all comparable to that

existing in the surface layers of the earth. The reason for this seems to be that at the surface of the earth bacteria secure at the same time oxygen, moisture and food — the most favorable conditions for their life. It appears to be very doubtful if bacteria are preeminently aquatic. Many species at any rate seem to inhabit the surface layers of the earth, and if, as appears to be the case, they are largely and perhaps preferably terrestrial, this, as we shall see, is a matter of great consequence in the establishment and conservation of the purity of waters.

The rain-drop arriving upon the porous earth is at once greeted by a hungry population of bacteria mantling the sand grains over which it is spread; and this, too, a permanent, not a nomadic, population. More or less slowly it sinks through this living, gelatinous layer, and as it passes on it is robbed of its suspended organic matters and of some of those in solution. It is also mechanically filtered to some extent, no doubt; but the main thing is that as a result of its journey, it is so purified in respect to its organic matters that it can no longer support abundant bacterial life. Meanwhile it readily dissolves the end-results and the by-products of the luxuriant bacterial vegetation through which it passes, and becomes the vehicle of nitrates, sulphates and other mineral matters. As it sinks lower and lower, it dissolves more and more of such salts, and, passing by other resident bacteria, is increasingly purified of organic matters capable of supporting bacterial life. Such water may contain bacteria, but, as abundant experiments have shown, these are relatively few in number and singularly slow of development. Water derived from deep wells is generally poor in bacteria, and even when not poor, is characterized by certain peculiarities which remove it from the category of waters charged with ordinary bacteria. In the case of most ground waters, a high degree of organic purity is established by the natural processes just described; and if such waters be collected in protected springs, wells, or covered

reservoirs properly constructed, their organic purity is readily conserved, and they constitute (in such cases) some of the most satisfactory water supplies known.

There are, however, certain conditions which limit the usefulness of "ground" waters. In the first place, while of high organic purity, they may have become so rich in inorganic matters as to belong to the class of "hard" or "mineral" waters, which, by common consent, based upon general experience, places them in the category of undesirable waters, inferior for public supplies. Far more important, however, is the fact that such waters are necessarily limited in quantity and, therefore, not often available for great cities. Obviously ground water can occupy only the interstices of the earth's crust, is subject when drawn upon to high friction, and therefore moves with slow velocity, so that from any one point, or from a few, only a limited amount of water, and that at a low rate of flow, can safely be counted upon. Great cities, however, require large quantities of water, and often large quantities within a very short time; so that it is easy to see why, for them, ground waters, will seldom, if ever, be adequate sources of supply.

On the other hand, ground waters may be polluted instead of purified by their passage through the earth. If the earth is itself impure or overtaxed from leaky cesspools, sink drains or other sources of foulness, natural purification may give way to unnatural pollution. This is the accepted theory of the pollution of domestic wells. But, in view of the remarkable purifying powers of the earth, and the almost total lack of satisfactory evidence of disease arising from pollution thus effected, the author is strongly of the opinion that the damage done by underground pollution of domestic wells has been greatly exaggerated. Excepting in those rare cases of fissures in the earth which give easy access for pollution from the surface, and excepting pollutions which have come in from the open top, he

is, and long has been, very sceptical concerning much of the damage attributed to domestic wells. It is very much to be feared that more harm has been done in these cases by throwing investigators off the true scent than by the pollutions themselves, real or imaginary.

Much more serious than pollutions of the soil are the dangers of infection of ground waters from workmen within wells themselves, such as happened, for example, in the well-known Caterham (England) case reported upon by Dr. Thorne-Thorne. In this instance it appeared that the bowel discharges of an incipient or "walking" typhoid patient, a laborer in one of the open wells supplying the towns of Caterham and Red Hill, found direct access to the pipes, and brought on a severe and widespread epidemic among users of this ground-water supply. (For an account of this epidemic, see pp. 191–200.)

§ 6. — *The Conservation of Purity of Ground Waters*

Finally, ground waters have the serious defect, that in order to remain pure after collection, they often require to be kept in the dark. The cities of Newton and Brookline, Mass., derive ground-water supplies of great organic purity from driven wells in an uninhabited district of the Charles River valley. But in order to conserve a purity established by natural filtration, these cities have had to build costly covered reservoirs; because on exposure to the light, such ground waters become infested with chlorophyl-bearing microscopical organisms (diatoms, desmids, etc.), which in turn support noxious infusorial animals, and give rise, not infrequently, to highly disagreeable and even nauseous tastes and odors, sometimes described by the consumers of the waters as resembling "cucumbers," "fish-oils," "pig-pens," etc. The conservation of the purity of ground waters thus often becomes a matter requiring expert treatment.

§ 7.—*Surface Waters and their Pollution*

Let us now turn to that class which we have called "surface" waters, and have described as characterized by a more or less horizontal movement of their particles after these have fallen upon the earth. In this case, the water which falls upon the surface, more or less impure from aerial pollution, instead of being subjected immediately to a progressive purification by sinking into the earth, moves along the surface of the earth, which it erodes, growing in volume as it proceeds, and forming rills, rivulets, or larger streams,—brooks, creeks, and rivers,—which still continue to move along the earth's surface, exposed to all sorts of pollution, until they pause for a longer or shorter time in ponds and lakes, or finally join the sea. The area over which this process goes on is called a "watershed," and much of the water which falls as rain or snow is thus shed off, as from a roof, without ever having soaked into the porous, purifying earth.

But it would be a mistake to suppose that the entire volume of brooks, rivers, and lakes has been thus derived. The greater part, even of the so-called "surface" waters, except in times of freshet due to sudden thaws or to heavy and prolonged rain, is really ground water, purified by a shorter or longer passage through the porous earth. It cannot be too strongly emphasized that a very large portion of the water of all rivers, even of those most polluted, is highly purified ground water; and this fact serves well to show how very impure the really surface-water portion of such streams must be. Other things equal, a water derived from a quick-spilling watershed must always be relatively impure and dangerous, because to the natural impurities of rain water have been added the surface impurities of the earth, violently detached and rapidly conveyed.

It will be clear, therefore, at the very outset, that the problem of the establishment of purity of surface water is

by no means easy. At first sight it would even seem that the larger a river is the more polluted it must be; for it has the longer been exposed to the manifold sources of pollution on its shores and from its tributaries, while as it flows no obvious sources of purification exist. A river to the casual observer seems like a great *vena cava* receiving a host of tributary veins, each of which has simply drained its own area; or like a *cloaca*, receiving drainage from a thousand lesser drains.

§ 8. — *The "Self-purification of Streams" Again*

How, then, we may well ask, did it ever happen that many well-regulated American cities, some of them of large size, have in the past drawn their water supplies from polluted rivers or lakes, not heedlessly, but on the advice of the ablest engineers and sanitarians of the day? The answer is that these engineers, in common with the best sanitarians of the time, trusted to a theory of the establishment of purity in surface waters, which we now know to have been only a half-truth and utterly untenable; namely, the theory of "self-purification" of streams. In substance this theory was, that "running water purifies itself." It was based on the obvious fact that a stream befouled at a certain point often shows no visible sign of such defilement at places some distance below. It was powerfully supported, however, and seemingly established as a law of nature, by the chemistry of the day, which sufficed to show, in correspondence with the evidence of the senses, that there was actually less organic matter at the lower than the higher point. Here, plainly, was actual scientific proof of purification — or what seemed to be such. Relying upon this theory, many cities — and some of them great cities — in America and elsewhere introduced water supplies from polluted streams, relying simply upon the self-purifying power of running water to

destroy the pollutions known to be poured into the streams at points above (*cf.* p. 129).

To-day we realize that this theory is only half true, and that such self-purification is only partial and absolutely unreliable. By a curious reversal of scientific opinion, we now hold that it is precisely "running" water which is least likely to purify itself, while stagnant (standing) water — formerly looked upon with dread and suspicion — is now in much favor. The old theory was in vogue long enough to enable us to make a wonderful series of experiments, and on a stupendous scale — experiments in which whole cities confidingly used for years sewage-polluted waters, often with sad results, yet results of lasting instruction to mankind. Never again, so long as civilization endures, will intelligent communities, acting under expert advice, need to repeat these sad experiments. The lesson was painful and costly, but it has been learned, and will never be forgotten.

The source of error in the earlier practice was in the neglect of the factor of dilution, with the assignment to true purification and actual chemical change of what was really for the most part dilution by ground water, which, as has been said above, not only forms a large proportion of the volume of most rivers, but also brings to them water of a high degree of organic purity. In so far as a mixture of pure water with foul can purify the latter, there is truly a marked "self-purification" of rivers. There is even more than this in fact, for some of the pathogenetic elements disappear *en route* from cold, or inanition, or by entanglement, or by falling to the bottom, or by the germicidal influence of light, or from other conditions, all of which may be summed up in the words "unfavorable environment." But, obviously, the more rapid the stream, the less such conditions of whatever kind can act, and the more certain the damage likely to be done to the consumers of the water below.

§ 9.—*Quiet Water, not Running Water, Purifies Itself*

It is therefore not so true that "running" water, as that quiet water, purifies itself. We may even go so far as to say that the first requirement for the natural establishment of purity in surface waters is quiescence. But quiescence in rivers is ordinarily impossible. Hence the establishment and conservation of purity in rapid rivers is to-day regarded as, by natural means, impossible; and no river, unless from an absolutely uninhabited watershed, is to be regarded as suitable for direct use as a public water supply.

§ 10.—*Natural Processes of Water Purification*

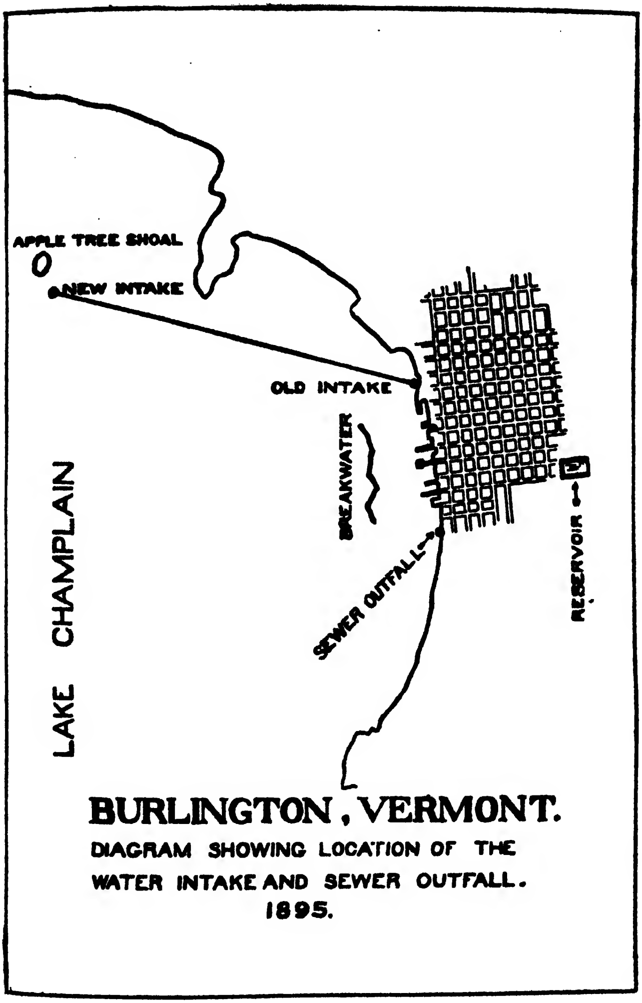
Fortunately there exist, nevertheless, purely natural processes by which the water even of polluted rivers, though not in the rivers themselves, can be readily purified on a large scale; and it follows that such streams may become available, although of course never directly, as valuable sources of water supply, even for great cities. The time has forever gone by when a city or town can honestly pump the water of an ordinary river at its doors, without any previous purification, directly to its citizens. On the other hand, we probably understand to-day better than ever before the nature of the processes required to effect the purification which is so indispensable. In fact, we have abundant and positive evidence, not only from the data afforded by the bacteriology of natural waters, but also from the actual experience of cities which have used such waters, that there are purely natural processes available, which under certain conditions are capable of producing a high degree of purification of polluted surface waters. These processes are of great scientific as well as practical interest, and deserve our most careful, if necessarily brief, consideration. We may dwell accordingly, first, upon the purification effected by simple quiescence,

as this is obtained in nature in lakes and ponds and as it can be effected, even for rivers, by artificial storage.

A case of this first kind is that afforded by the public water supply of Burlington, Vt. Burlington is the only city in New England which derives its water supply from the same lake into which it empties its sewage, although this arrangement for water-supply and sewage disposal is common enough in other parts of the United States, such as Chicago (until 1900), Milwaukee, Duluth, Buffalo, Cleveland, and in Toronto, Canada. Burlington is situated at the eastern extremity of a broad bay on Lake Champlain, and when, in 1866, the citizens determined to have an ample public water supply for fire and other purposes, they naturally turned to the lake (*cf.* p. 132.)

The waterworks were built in 1867, the intake being located on the lake front, near the northern extremity of the docks. For some years the water supply gave entire satisfaction, and in 1870 the health officer reported that at no time had the city water supply held so high a place in the public estimation. When sewers were put in, the trunk sewer, carrying most of the sewage of the city, was made to empty into the lake about one-half mile south of the water intake; and although there was gradually an increasing conviction, based upon the evidence drawn from the prevalence of diarrhœa and dysentery, with a small amount of typhoid fever, that things were not altogether satisfactory, matters did not become bad enough to cause the removal of the sewer outfall to a more remote point until 1885, when it was carried to a place one mile, instead of one-half mile, away from the intake of the waterworks.

Meantime the city had increased in population, and the sewer connections with dwellings had multiplied; but even as late as 1892, while strongly disapproving of the local conditions, and urging most emphatically a change in them, the author himself, after a very careful investigation,


APPLE TREE SHOAL
NEW INTAKE
OLD INTAKE
BREAKWATER
LAKE CHAMPLAIN
SEWER OUTFALL
RESERVOIR
BURLINGTON, VERMONT.
DIAGRAM SHOWING LOCATION OF THE
WATER INTAKE AND SEWER OUTFALL.
1895.

was forced by the facts to report to the city officials, that so great was the purification accomplished by this one mile of lake quiescence that there was no immediate reason for excessive anxiety or alarm for the sanitary condition of the water supply. He reported among other things that "the results show conclusively that the mortality from typhoid fever, — and the same is true for diarrhœa and dysentery, — has not been large in Burlington during the last twelve years. The average annual mortality from typhoid fever from 1870 to 1891 was 3.57 per ten thousand inhabitants." He then went on to show that Burlington compared favorably in this respect with many cities having water supplies of undoubted purity, and stated that in respect to mortality from typhoid fever it had a better record than many cities having water supplies of good reputation. He added, that during the past three years he had repeatedly made bacteriological analyses of the Burlington supply, and had found no satisfactory evidence of the presence of sewage in the drinking water. In spite of these facts, however, he urged that the location of the intake of the waterworks as near as it was to the main sewer of the city was highly objectionable, if not positively dangerous, and that he regarded it as a constant menace to the sanitary welfare of the city.

Now how had it happened that such extensive befouling of the lake front, only one mile, and for some years only one-half mile, from the intake of the drinking water of the city, had done so little harm? The answer is that here, precisely as in many rivers which were formerly supposed to have purified themselves by "running" or exposure to free oxygen, *dilution* with pure water did much; and, what was not true in the case of the rivers, *quiescence* did far more. Bacterial analyses showed that at the sewer outfall the numbers of bacteria were millions, and the kinds had clearly marked sewage characteristics. But at points one hundred feet away ninety per cent of these had disappeared,

and at one thousand feet many more. At the distance of half a mile nearly all trace of sewage had disappeared, and a mile away no evidence of it could be found. It should not fail to be stated that in the Bay there are no regular currents, but only wind currents setting sometimes in one direction, sometimes in another; and that the amount of sewage poured in from a city of the size of Burlington is not very large, as it then had only about fifteen thousand inhabitants.

Furthermore, the sewer outfall opened into a small pocket or basin of its own, where lively fermentation went on in summer; and this was an added purifying agency, though dwellers in the neighborhood complained bitterly at times of the evil smells arising from this little basin. The fact, however, that in this pocket the sewage lingered quietly for a time, and fermented more or less, was undoubtedly favorable to its purification. When, a year or two later, it was determined to do away with this basin, the citizens were warned of the added danger involved, and finally were persuaded to carry the intake pipe of their water works three miles out into the purer waters of the broad lake.

It is certainly a remarkable and highly important fact, that under certain conditions a city or town — but always one of small size only — may safely drain into, and drink from, the same lake, — a condition which may be forcibly described as drinking from the other side of its own cesspool. This is, in fact, what is done by such cities as Duluth, Cleveland, Chicago (up to 1900), and Milwaukee; but it is important to remember that it can be done with safety only by *small* communities, for the reason that the greater the city the nearer we come to a quick circulation — a river of sewage flowing out, a river of water flowing in, — and the danger of contamination here increases with the volumes. If it increases so far as to do away with sufficient *quiescence*, we have once more estab-

lished what is essentially a stream, and running water, as we have seen, does not effectually purify itself — it mainly undergoes dilution.

§ 11.—*Purification by Storage*

Conversely, if a running water such as we have in a river can be converted into a quiet water, — as in a reservoir, — just such purification as we have discovered in Burlington may result. This is, indeed, what takes place, fortunately, with water derived from polluted watersheds and stored in huge reservoirs, — great and often adequate purification may be established by prolonged quiescence, or storage. There is every reason to believe that the principles involved in the purification which goes on in Burlington are typical in whole or in part of many other similar cases. Some bacteria perish almost immediately in the cold water of the lake; some settle to the bottom and perish there; some are killed by light as they float on the surface; some are devoured by predatory infusoria; the more hardy survive, perhaps, but do not multiply because of lack of food and other unfavoring conditions, and so are simply scattered by dilution; until finally only those remain which can permanently thrive in the now relatively pure water; and these are apparently mostly harmless.

§ 12.—*Purification by Slow Sand Filtration*

It follows as a matter of course, from what has now been said, that if a city or town must use a river as its source of supply, it must ordinarily first purify it either by natural or by artificial means. One of the natural processes available has just been described, and may be summarily characterized as *quiescence* effected by prolonged "storage." Another process may be defined as "natural filtration." Thanks to the labors of the State Board of Health of Massachusetts, and to the intelligence of the people of

that State who have supplied the necessary funds to carry on what was perhaps the most elaborate and costly series of experiments hitherto undertaken in the interests of sanitary science, we are to-day in full possession of the data which enable us to define with certainty the natural laws governing the artificial purification of surface waters by simple sand filtration. These are now a matter of common knowledge among experts, and therefore need not be dwelt upon at length at this point. Stated in a few words, we may say that the process of purification by "natural filtration" is accomplished precisely as is the case with the rain falling on porous earth (p. 226).

Land of porous texture is first prepared, sand having been found preferable for the purpose, while in the best practice specially constructed "areas" or "beds" of sand are made and then thoroughly underdrained, so as to facilitate the collection of the purified water. The water to be filtered is allowed to run over the surface and find its way down through the open, porous sand. Very soon, however, bacteria take up their residence on the sand grains, especially near the top, bacterial jelly accumulates, and a purifying mechanism or organism of great efficiency results. If this mechanism be operated intermittently, air passes into the interstices of the sand, precisely as into ordinary earth, only more freely; and some of the organic matters are removed by nitrification, that is, by complete conversion into mineral matter. In this case, also, the bacterial jelly forms, but farther down in the sand, and makes an effective purifying medium.

Innumerable tests of such mechanisms as this have been made and their high efficiency shown. They are usually called sand "filters," but the name is unfortunate as implying something artificial rather than natural. The process is, in fact, nearly if not exactly the same as in the purifying of surface waters which pass through earth and become ground waters; although by selecting the porous materials,

"hardness" and some other faults of ground water are avoided. It is by such means that London, Hamburg, Berlin, and Lawrence in Massachusetts, secure from polluted surface waters satisfactory and sanitary supplies. Albany has followed in their footsteps, and Washington, Philadelphia and many other American cities must probably do likewise. For the establishment of purity in surface waters, we have, then, two important and natural processes, — "storage" and "sand filtration."

§ 13.—*Artificial Processes of Purification of Water Supplies*

Various attempts have been made to substitute artificial for natural processes of purification of water supplies, and, under certain circumstances, there can be no question of the importance or value of these procedures. The only processes of this character thus far seriously proposed are those known in America as processes of "mechanical" filtration, for which the advantages are claimed of, first, rapidity; second, hygienic efficiency; third, removal of clayey turbidities and thorough decolorization; fourth, convenience of installation; fifth, cheapness. The principles involved in mechanical filtration are comparatively simple, being substantially as follows: a chemical reagent of presumably harmless character, such as alumina, is added in a certain small proportion to the water to be purified, yet sufficient to produce, if the reaction of the water be right, a flocculent precipitate. If the water were kept quiet and allowed to stand, this precipitate would entangle and carry to the bottom a large amount of the suspended matters present, including the bacteria. In fact, however, this is not found to be necessary, but after the addition of the coagulant the water is rapidly passed through a sand filter upon the surface of which the flocculent precipitate mentioned quickly collects and forms a layer. This more or less effectually detains suspended matters, including the bacte-

ria, and removes from the water a large amount of any color which it may contain. Mechanical appliances, such as the reversal of the stream, allow for the washing of the sand filters and for the repetition of the process, which may obviously be carried on rapidly and therefore upon a comparatively small area.

§ 14. — *Hygienic Efficiency of Rapid Mechanical Filters*

Tests of the hygienic efficiency of rapid mechanical filters were formerly, for the most part, wanting, but experiments made on the water of the Ohio River at Louisville, Ky., and Cincinnati, O., and upon one of its tributaries, the Allegheny River at Pittsburgh, Penn., have shed much light upon the subject.[1]

§ 15. — *Conservation of Purity in Surface Waters*

Enough has been said to show that the natural establishment of purity in water supplies is a process somewhat elaborate and complicated. The conservation of the purity of ground waters, when once they have been collected, has already been shown to be a matter requiring intelligent supervision (p. 229). The same thing is equally true of surface waters, especially those required for great cities. If, after collection, these waters are stored in huge reservoirs rich in organic matter (as is usually the case), they not infrequently become infested with microscopical organisms which generate in them disagreeable, and sometimes even nauseous, tastes and odors, of which the consumers bitterly and very properly complain. The supply of New

[1] Reports have appeared upon all of these experiments, namely, upon the purification of the Ohio River at Louisville and at Cincinnati, by George W. Fuller, on behalf of the Water Departments of these cities, respectively, and at Pittsburgh by Allen Hazen on behalf of the Filtration Commission of the city of Pittsburgh. Those interested in the details of this subject are referred to these reports.

York City is collected from watersheds by no means uninhabited, and is in many respects well purified by storage. Until very recently, however, it has not been thought necessary, even if it is to-day, in New York, to remove all possible organic matter from the storage basins or reservoirs employed.

The latest and best practice, however, is exemplified by the great Metropolitan supply for Boston and the twenty-eight cities and towns in its immediate vicinity. There the large Wachusett reservoir, which alone is to cost $9,000,000, is now (in 1901) being carefully prepared, by the removal of all peat, muck, stumps, loam, and other organic matter, from the sides and bottom of the reservoir, in order that organic matters may be lacking for the support of these same microscopical organisms during storage. For this specific purpose of "stripping," as it is called, it is estimated that $3,500,000 will be spent. In this case, which probably represents the most advanced ideas in the establishment and conservation of purity in surface waters, great pains are being taken:—

1st. To secure water originally of high organic purity.

2d. To keep the watersheds as uninhabited as possible.

3d. To purify the water collected, by long storage in an immense reservoir; and,

4th. To conserve its purity, when this has once been established, by having the reservoir at the start as free as possible from organic matters which might support bacteria or microscopical organisms.

§ 16.—*Recapitulation*

We may point out briefly, in review, the practical application of the principles now laid down, to the water supplies of great cities, which, as has been shown, must, for the most part, be surface waters. The aerial pollutions, if any, may be neglected, because beyond our control. But

with the principal source of pollution, the watershed, it is quite otherwise. Obviously the watershed largely determines the character of the surface water. The watershed may be uninhabited, or thickly or thinly inhabited. It may consist of swampy, peaty or manured soils; or of forests, rocks and barren slopes; or of a combination of such things; and upon these conditions will depend largely the character, purity and conservation capacity of the water collected. It is rarely the case that a great city can secure for its water supply a totally uninhabited watershed, or one free from swamps or other accumulations of organic matter. Where a choice is possible, it should as far as practicable do this. In the ideal system of surface-water supply, the city should own the entire watershed, and keep it clean and uninhabited. But if, as will usually be the case, the watershed is more or less inhabited and swampy, pains must be taken to guard against specific pollutions from habitations, and to drain swamps, so as to collect the rainfall from the former as slowly, and from the latter as quickly, as possible. For all the details of these matters, the most intelligent and educated sanitary supervision are required. This is the place for young sanitary engineers who, as careful scientific inspectors, should be employed, not occasionally or spasmodically, but regularly and permanently, to guard the sanitary condition of watersheds. To bring about even the possibility of this, special legislation may be necessary, as for example was found to be the case in Massachusetts, where formerly the law did not allow any city or town, or any sanitary authority on their complaint, to abate nuisances or remove sources of pollution upon any part of the watershed from which it derived its drinking water. Afterward a statute was enacted, making it possible, by due process of law, for the State Board of Health (on complaint) to remove sources of pollution "within the distance of one hundred feet of the high-water

mark of any stream or pond, or any stream, pond, spring, or water-course tributary thereto, polluting or tending to pollute such stream, pond, spring, or water-course."

§ 17.—*Protection of Purity of Inland Waters in Massachusetts*

The progress of legislation toward the better control, or sanitary protection, of watersheds is interesting and instructive, as it is laid down, for example, in the Massachusetts statutes.[1]

Previous to 1878 there was apparently in Massachusetts no attempt to guard against pollution of public water supplies, still less of the watersheds from which they were derived; but in that year it was made illegal to discharge into any stream or pond used as a source of water supply polluting material within twenty miles above the point where the supply was taken. We see here embodied in legislation the influence of the old theory of "self-purification"—twenty miles having been formerly regarded as an ample distance within which a stream might purify itself.

In 1879 it was made illegal to deposit excrement or foul or decaying matter in any water used for domestic water supply on or upon the shore thereof within five rods of the water; but it was also specially provided that this act should not be construed to interfere with the putting in of the sewage of a city, town or public institution, or to prevent boating, bathing or fishing, or the enriching of land for agricultural purposes.

It was not until 1890 that any legislation of a thoroughly modern sort, in harmony with the sanitary science of the day, was enacted, and this was of the limited description

[1] The English Public Health Act of 1875 took very advanced ground on this subject, and was doubtless the model after which much of the Massachusetts law was shaped.

already referred to, inasmuch as it restricted the powers of the State Board of Health, as a sanitary authority to be appealed to, to the limit of one hundred feet from the high-water mark of any stream or pond, or any tributary of the same. This was, of course, a distinct advance; but with the inauguration of the Metropolitan Water Supply for Boston and vicinity, special legislation was secured for that area, which provided *absolute control* by the State Board of Health over the sanitary condition of the *entire watersheds* which it was proposed to use.

§ 18. — *Sanitary Protection of Public Water Supplies*

In Chapter 488 of the Acts of the General Assembly of Massachusetts for the year 1895, to provide for a Metropolitan Water Supply, an advanced position was taken in regard to the sanitary protection of water in Massachusetts in the following sections: —

SANITARY PROTECTION OF WATER

SECTION 24. The State Board of Health is hereby authorized and required to make rules and regulations for the sanitary protection of all waters used by the Metropolitan Water Board for the water supply of any city, town, or water company aforesaid. . . .

ENFORCEMENT

SECTION 27. Said Metropolitan Water Board and their employees designated for the purpose shall enforce the provisions of this act, and of the rules, regulations, and orders made thereunder, and may enter into any building, and upon any land, for the purpose of ascertaining whether sources of pollution there exist, and whether the provisions of this act and of the rules, regulations, and orders made as aforesaid are complied with. . . .

In 1897 what was practically the same authority was granted to the State Board of Health, covering all watersheds within the state of Massachusetts tributary to public water supplies, in the shape of an act, Chapter 510, Acts of

1897, which reads as follows, and probably represents, as nearly as can be expected in conservative legislation, the best ideas of the sanitary science of to-day on this subject.

ACTS OF 1897. CHAPTER 510

An Act relative to the Pollution of Sources of Water Supply

Be it enacted, etc., as follows: —

SECTION 1. The State Board of Health shall have the general supervision of, and have authority, from time to time, as it may deem expedient, to examine all streams and ponds used by any city, town, or water or ice company in this Commonwealth as sources of water supply, together with all springs, streams, and water sources tributary thereto, with reference to their purity, and shall have authority to make rules, regulations, and orders for the purpose of preventing the pollution, and securing the sanitary protection of the same.

SECTION 2. Said Board shall appoint such agents and servants as it may deem necessary, who shall attend to the enforcement of the provisions of this act and of the rules, regulations, and orders thereunder, and shall have the power, by such agents and servants as aforesaid, to enter into and upon any building structure and premises for the purpose of ascertaining whether or not any sources of pollution or danger to the water supply there exist, and whether or not the provisions of this act and the rules, regulations, and orders made as aforesaid are complied with and obeyed. . . .

SECTION 3. Upon complaint to said State Board of Health by the mayor of a city or the selectmen of a town, or by a board of water commissioners, or by the president of a water or ice company, that manure, excrement, garbage, sewage, or any other matter is so deposited, kept or discharged as to pollute or tend to pollute the waters of any stream, pond, spring, or water-course used by a city, town, water or ice company as a source of water supply, or that any other cause of pollution to such water supplies exists, the said Board of Health shall appoint a time and place for hearing parties to be affected, and give due notice thereof to such parties; and after such hearing, if in its judgment the public health requires it, shall prohibit the deposit, keeping, or discharge of any such material, or other cause of pollution as aforesaid, and shall order any person to desist therefrom and to remove any such material theretofore deposited, or other cause of pollution; but said Board shall not prohibit the cultivation and use of the soil in the ordinary methods

of agriculture, provided that no human excrement is used thereon. But said Board shall not prohibit the use of any structure which was in existence at the time of the passage of this act, in case the complaint referring to or including such structure is made by the board of water commissioners of any city or town, or by any water or ice company, unless the board of water commissioners or the water or ice company making the complaint shall file with the said State Board of Health an order or vote of its city council, selectmen, or water or ice company respectively, to the effect that such city, town, or water or ice company will, at its own expense, make such changes in said structure or its location as said Board shall deem expedient. Such order or vote shall be binding on such city, town, or water or ice company; and, when such changes shall have been made, all damages occasioned thereby shall be paid by such city, town, or water or ice company; and if the parties cannot agree thereon, such damages shall be determined by a jury on petition of either party, filed in the clerk's office of the superior court in the county where the premises are located, in the manner provided by law in relation to determining the damages occasioned by taking land for highways in such city or town, or in the case of a water or ice company, in the city or town in which the said structure is located. . . .

SECTION 6. Whoever does any of the acts herein prohibited or violates or refuses to comply with any rule, regulation, or order made under the authority of this act shall be punished for each offence by a fine not exceeding five hundred dollars, to be paid to the Commonwealth, or by imprisonment not exceeding one year in the House of Correction, or by both such fine and imprisonment.

This law was secured only after it had been found that, under previous legislation which had established a hundred-foot limit, it was quite impossible adequately to protect Massachusetts watersheds from pollution.

§ 19.—*Sanitary Protection and Inspection of Watersheds*

Of late years it has been also learned, at least in Massachusetts, that serious pollutions, similar to that which affected the ground-water supply of Caterham, England (p. 191), may occur in surface supplies from the temporary residence on the watershed of thousands of laborers, some of whom may be walking cases of infectious disease. Two

examples of this kind have occurred within the author's experience.

The first happened in 1894, while a new reservoir of great size was under construction for a large and important American city. When finished it was to be connected with and added to an existing system of reservoirs, and during the work of stripping off the loam and building the dam large gangs of men were, of necessity, employed. The stream which was to be dammed naturally ran through the valley where these men worked, and on into the lower reservoirs, constituting the then existing supply of the city.

An epidemic of typhoid fever broke out among the laborers. The author was called in to study the cause of the typhoid fever, but very soon saw that, valuable as such study might be from the ætiological point of view, the possible effects of the epidemic were practically far more important and pressing. He was sent to find the cause of the typhoid fever; but this question had to wait, as soon as he saw the true state of affairs, while he tried to prevent the typhoid germs produced by the people who were working on the brook, and using it as their sewer, from reaching the consumers of the water below. There were hundreds of men at work, and a large number of them were suffering with typhoid fever. All were living or working about or very near the brook. Many were visibly using it as a drain and a defecating place, and were defiling its shores at various points from which material during a sudden shower was readily washed into the brook and conveyed to a reservoir below. Fortunately the system of reservoirs allowed this one to be disconnected for a time. The purifying effects of quiescence and storage were called in. The watershed was cleaned up, disinfection was employed, and every possible precaution taken to prevent further trouble. It is pleasant to be able to record the fact that the efforts of those concerned were entirely successful.

The other case was very similar. Another large city was

building a huge storage reservoir. Two thousand laborers were employed and lived upon the watershed, close to the stream which was to be dammed up. Typhoid fever broke out among them. They were very ignorant, and even when closely watched persisted in washing their soiled clothing in the brook which ran down into the city supply below. Extraordinary pains had to be taken to make sure that the purity of this infected supply was reëstablished and conserved before it was delivered to the consumers. The chief responsibility in this case, also, fell upon the author, who was fortunately successful in his efforts to prevent infection from reaching the users of the water.

Still another lately recognized source of pollution of watersheds is their use for picnic purposes and summer resorts. In 1896 the attention of the State Board of Health of Massachusetts was called to this subject, and the author had the privilege of supervising a general investigation of the sanitary condition of all the picnic and summer resorts of the state, but especially those located on the watersheds of public water supplies, with a view to learning the character and extent of the pollutions, if any. The results showed that in many cases dangerous pollutions existed upon the watersheds, seriously imperilling the purity of the supplies with which they were connected. In the following year the work was repeated, with equally satisfactory results. The development of electric street railway systems has, in Massachusetts at least, caused many new "resorts" to spring up in out-of-the-way places (often chosen largely because of their isolation and wildness), and in not a few cases on or near lakes and reservoirs used for water supplies, or upon their watersheds.

Far more serious, of course, are those instances in which villages or towns are situated within or upon a watershed. These cases often require the most careful study and supervision. Sometimes it is necessary and possible to divert their drainage from the watershed; sometimes, when this is

impracticable, it can be purified on a sewage farm within the watershed; sometimes other procedures are required. Here again intelligent supervision and control are required, which must be permanent, inasmuch as the conditions on the watershed are subject to frequent and often unexpected change. Few American cities, if any, have to-day such supervision as the standards of modern science demand. It is not enough to burn occasionally a few barns or to purchase and remove a few pig-pens on the watershed. The problem is larger than this, and requires thoughtful, enlightened and continuous public service for its proper amelioration.

After the careful collection of the water from the watershed, it should be subjected to one or the other, or both, of the two great methods of natural purification — storage or filtration — in order to correct whatever defects it may still possess. If it be a ground water, further filtration is generally needless, but its storage must be effected in the absence of light. If it be a surface water, it should without question be stored for a time and, when possible, in well-stripped reservoirs, *i.e.* in reservoirs freed from organic matters.

A wise writer, it will be remembered, has recommended "old books to read, old wine to drink, old wood to burn." It has since been discovered, in addition, that old water is better than new. It is said that the old-time sea captains seldom allowed any water to be used on board ship that had not been in the casks for months. The theory was that water, like wine, underwent a "working" or fermentation which improved its salubrity. We now know that they were right, and, better, we know why: it was simply that harmful bacteria were given ample time to die out.

If a surface water is known to be much polluted when collected, the more difficult and more heroic treatment of filtration should be invoked. Here again, in any particular case, experience and judgment are required. London

first stores and then filters, with excellent results. Hamburg does the reverse, and so does Lawrence, and when practicable, storage, both before and after filtration, is probably desirable and useful.

§ 20. — *Expert Supervision an Absolute Requirement of Modern Sanitation*

The keynote of public service is expert supervision. With this remark we return to the point from which we started. If a public supply is to be made a public blessing, it must be scientifically and skilfully, as well as economically, administered. It will not do to leave to the shifty devices of petty politicians matters like water supply, gas supply, and food supply, which require, for mere public safety, skilled and highly paid supervision. If democratic government is to endure and to exemplify a form of civilization above that of the republics of Central America, in which plunder and bad government are the rule, the people must see to it that in the place of small politicians to manage these things, they have educated public servants; instead of neglecting to care for watersheds, these must be supervised by men technically trained; and instead of bosses and heelers to deal with these problems in their larger aspects, there must be faithful and able experts. Only on this condition can we afford to surrender private supervision of some of the principal avenues of our well-being for public supervision; and until the most expert public supervision attainable takes the place of private control, it will remain true that a public supply is a public danger. (Cf. p. 221.)

CHAPTER X

ON ICE AS A VEHICLE OF INFECTIOUS DISEASE. THE POLLUTION OF ICE. ICE SUPPLY AND THE PUBLIC HEALTH [1]

§ 1. — *The Mingling of Melted Ice with Food and Drink*

THE almost universal American custom (now rapidly spreading in Europe) of cooling certain drinks — such as water, lemonade and tea — by adding to them lumps of ice, which are allowed to melt and mingle with liquid to be swallowed, early attracted the attention of sanitarians, to whom the idea naturally occurred that if the ice thus added be impure, serious consequences may result. The amount of ice consumed in this way in America alone during the warm season, and indeed all the year round, is simply enormous. It is the almost invariable rule in hotels and restaurants to begin the service of a guest at table by filling his glass with broken pieces of ice or "cracked" ice, and at least one observer of American life and manners has cleverly commented upon this almost national habit.[2] In some clubs and hotels drinking water is put upon the table in the shape of glass water-bottles (carafes), in which the water has been frozen solid, filling the bottle with one solid mass of ice. This gradually melts during the meal, and the water which is poured from it for drinking in this

[1] This subject is treated at much length, and with full references to the literature, in a paper by the author and C.-E. A. Winslow, S. M., recently published in the Memoirs of the American Academy of Arts and Sciences in Boston, Vol. XII, No. V. Frequent extracts from this paper are made in the present chapter.

[2] . . . "Ice-water, the musical tinkling of which in the corridors is the most characteristic sound of the American caravanserai." — J. F. MUIRHEAD, "The Land of Contrasts," Boston, 1898.

case comes wholly from melted ice. Pleasure parties, excursion parties, and the like often make use of large tubs of drink (water, lemonade, etc.), into which a cake of ice is put bodily; and this, in melting, not only cools the surrounding liquid, but contributes to it whatever impurities it may contain. Raw oysters (removed from the shell) are sometimes placed upon a luncheon or dinner table in a cubical cavity, cut into the top of a large block of ice, and are later served with more or less of the meltings of the sides and bottom of the ice-cavity in which they lie. It is plain that if the germs of infectious disease or other impurities can survive in ice, this when melted may form a ready vehicle for the distribution of disease.

§ 2.—*Does Polluted Water purify itself in Freezing?*

It is a popular belief that, at least in many cases, the ice which forms upon a body of water is purer than the water itself. This belief is probably based in part upon the well-known fact that when a substance crystallizes out of a liquid the crystals formed are usually purer than the mother-liquor from which they come; and general reliance seems to have been placed (in America) upon this tendency to purification to which ice crystals also might be expected to be subject, until, in 1887, careful investigations by Prudden showed that bacteria are not wholly eliminated from ice in the freezing of water, and that these may even survive in ice for long periods. It was then remarked that ice often contains visible impurities, and if these, why not also others invisible?

A little reflection will show that the question of elimination of impurities such as bacteria, which are really suspended particles, depends for its solution upon a variety of conditions. If, for example, the body of water, *e.g.* a small lake or pond, containing bacteria be frozen absolutely solid, as in the case of the carafes of drinking water mentioned

above, there is no reason to expect elimination during crystallization, for there is no place into which the bacteria can be extruded by the growing crystals. But if the ice in question is formed on the surface of a quiet lake or pond, the very first skimming of crystals produces absolute quiescence in the underlying layers of water, and gravity must then exert a powerful effect upon the floating bacteria. In this case there is abundant opportunity for the elimination of foreign particles by the growing crystals; and as these gradually extend downward, they will naturally first invade those layers of water nearest to themselves, which, for obvious reasons, may be the freest from bacteria, while the lower layers of the pond will contain not only the bacteria belonging to themselves, but also such as have been dragged down by gravity from the upper layers. Accordingly, the uppermost layer of such ice will often be the richest in bacteria; while the next lower ice layers, especially if their formation has been slow, may be relatively free from bacteria.

Again, to take another case: If, as is often done, the harvesters, after a few inches of ice have been formed, cut holes in the ice-sheet, allowing the subnatant water to overflow it, and by freezing solidly from above to become added bodily to that already formed, the conditions in the case of this added layer will be similar to those in the carafe. The mass will be frozen as a whole, and no mechanical elimination during crystallization can reasonably be expected. Lastly, if, after the ice has begun to form, snow falls upon it, and this, by a rainfall or a thaw followed by freezing weather, becomes added as a superficial layer of "snow-ice" to that upon which it fell, such "snow-ice" may be expected, from what has been said above (p. 224) in regard to the action of snow as an atmospheric filter, to contain large numbers of bacteria.

From these various considerations we may conclude that the answer to the question, Does water purify itself in

freezing? depends largely upon the conditions under which it is frozen. If ice is formed upon a quiet lake or pond of considerable depth, the water of the pond probably does purify itself to a marked degree in freezing. But if, on the other hand, the freezing takes place in such a way that sedimentation has little influence, or if an entire mass of water is frozen solid, purification may be much less marked, or even largely wanting.[1]

§ 3.—*Epidemics attributed to Infected Ice*

In spite of the fact that ice may contain very considerable numbers of bacteria, and that it has been hitherto regarded as a dangerous vehicle of disease, only a surprisingly small number of epidemics have been charged to infected ice; and a careful examination of the reports of these leaves upon the student the impression that the dangers of polluted ice have probably been exaggerated.

The first epidemic attributed to infected ice, and carefully investigated, occurred at a summer resort known as Rye Beach, New Hampshire, in 1875. The illness in question—a severe intestinal disorder—was confined to the guests of one of the large hotels. The milk supply, the water supply, and the drainage appeared to be above suspicion; but the ice supply had been derived from a small pond, the waters of which were rendered very foul by a mass of putrescent matter composed of a mixture of marsh mud and decomposing sawdust. Chemical analysis of the water from the pond and of the ice showed the presence of high total organic matter and high ammonias, both free and albuminoid. The inference was that the disease had somehow come from the ice. In 1878 Dr. Charles Smart, surgeon United States Army, attributed certain cases of

[1] See Thirty-second Annual Report of the State Board of Health of Massachusetts for 1900, pp. 510, *et seq.* Boston, 1901. Twenty-first Report (for 1889), p. 145, *et seq.* Boston, 1890.

"malarial remittent" fever in a Rocky Mountain army post to the contamination of mountain streams by melting snow. In 1879 an outbreak of dysentery occurred in Connecticut in a family of eleven persons residing in a farmhouse. There were in all eight cases of disease, of which three proved fatal. This epidemic was charged to ice which had been cut on a small stream used as a running-place for pigs. In 1882 a single case of typhoid fever charged to ice occurred in the same state. The patient lived otherwise under excellent sanitary conditions, but was much addicted to iced water, of which he consumed large quantities, the ice having come from a pond into which drains from some laborers' houses emptied. In these houses there had been three cases of typhoid fever during the previous summer. Excepting the Rye Beach epidemic already mentioned, the most notable epidemic of disease connected with frozen water (snow) is that of typhoid fever in Plymouth, Penn., in 1885 (cf. pp. 200–206). In this case the epidemic, which was of very large proportions, was clearly traced to the pollution of the public water supply by the dejecta of a single patient suffering from typhoid fever. Moreover, these dejecta had been thrown, without disinfection, upon the snow which covered the ground near the house in which the patient lay ill, and had, in part at least, probably been thoroughly frozen. When finally the mass was melted by the arrival of warmer weather, and had been washed by rains into the public water supply, a very extensive and serious epidemic ensued. It appears, however, that while the earlier dejecta were thus almost certainly exposed to a very low air temperature, the same cannot be said of the excreta thrown out just before the "thaw" occurred; so that it is by no means certain that all were exposed to a freezing temperature. Besides, fæcal matters frozen solidly *en masse* are very unlike ice, properly so called, or such as is used for public ice supply, and the former might easily be a much more favorable medium for

the viability of microbes than the latter. Accordingly, even if we allow that the Plymouth epidemic was caused by germs which had resisted very low temperatures, it would not by any means follow that ice as ordinarily made and used is an important vehicle of disease.

Owing to the hitherto limited use in Europe of ice for cooling drinks, we should not expect to find on record many European epidemics charged to infected ice. The only one which need be cited here occurred at the military post of Rennes in 1895. Eight lieutenants of a regiment fell ill of typhoid fever between December 12 and 25. The fact that these officers did not ordinarily live in common, but had all attended a regimental banquet on December 4, pointed to something taken at that time as the vehicle of infection. The officers of higher rank, among whom no disease appeared, dined in a separate room and used for water only the town supply, which was excellent. The lieutenants on the other hand shared a "tisane" of champagne which they mixed with chilled water. It was supposed at first that this water was derived from the town supply, but afterward that it came from the melting of the ice used for general refrigeration; and this ice was believed to be highly polluted. The menu of the various classes of officers was the same, and certain of the petty officers who did not share the "tisane," but drank beer instead, were not attacked.

Reviewing the evidence, it seems probable that certain intestinal disorders caused by decomposing organic matters, if not by the more well-defined pathogenic germs, have at times been caused by polluted ice. The Rye Beach epidemic was carefully studied, and points directly to this conclusion. On the other hand, we have not been able to find much satisfactory evidence that typhoid fever or other well-known infectious diseases are carried in this way; but the possibility that some obscure "sporadic" cases are due to infected ice, cannot be denied.

§ 4.—*Investigations of the Purity of Ice by Various Observers*

As early as 1871 Professor Burdon-Sanderson observed that (liquid) culture media showed bacterial growth when inoculated with melted snow or ice. Von Frisch froze putrefying solutions, subjected the frozen mass to a temperature of $-87°$ C. and after the lapse of some hours found that sterilization had not been effected.

Professor Joseph Leidy in 1884 exhibited at a meeting of the Academy of Natural Sciences of Philadelphia water derived from melted ice containing not only living infusoria but also rotifers and other worms. Pictet and Young subjected various species of bacteria to a temperature below $-70°$ C. for 108 hours (during 20 hours below $-130°$ C.). After this treatment the cultures of *B. anthracis* and the bacillus of symptomatic anthrax were alive and virulent. Kowalski analyzed 60 specimens of natural ice and obtained from 10 to 1000 colonies per cubic centimetre, no specimen being sterile. Schmelk studied the bacterial life in the snow (and ice) of a Norwegian glacier and in the cold streams flowing from it. Bujwid found 21,000 bacteria pér cubic centimeter in a melted hailstone, and similar though smaller figures have been obtained by others (Foutin, Abbott). Heyrothin 1888–1889 obtained in the ice supply of Berlin from 2 to 133,000 bacteria per cubic centimetre, the highest figures corresponding to chemical analyses which showed the most marked pollution. Prudden in 1887 found in the natural ice supplied to New York City a wide variation in numbers. Many other observers have come to similar conclusions.

The author and his assistants in an extended investigation of the ice supplies of Massachusetts (see Report of the Massachusetts State Board of Health for 1889) found in the natural ice of that state (which is mostly obtained from ponds, lakes and rivers) very few living bacteria in the

clear ice of the upper layers, but considerable numbers in some cases in the lower layers and in the "bubbly" or "snow" ice. An examination of the artificial ice made in Massachusetts in 1892 proved the number of bacteria to be "insignificant under the prevailing methods of manufacture." (T. M. Drown, Twenty-fourth Annual Report State Board of Health of Massachusetts (for 1892), p. 598.)

It appears to be certain, therefore, that cold, even when extreme, cannot be depended on to kill all bacteria whether pathogenic or saprophytic; and both natural and artificial ice may, and generally do, contain more or less living micro-organisms.

§ 5.—*Ice as a Vehicle of Disease*

It is plain from what has been said in the last paragraph that ice may contain living pathogenic germs. It may therefore unquestionably be an important vehicle of disease. On the other hand, the literature of the subject fails to reveal any very clear evidence that it has been hitherto a vehicle of any great importance, while it is an indubitable fact that certain cities which have used ice cut from sources known to be infected with the germs of typhoid fever have not suffered perceptibly from that cause. According to Prudden, the ice supply of New York City was, in 1888, largely derived from the Hudson River — a stream highly polluted by the sewage of Albany, Troy and other places in which much typhoid fever existed. Yet a study of the vital statistics of New York City does not support the idea that much typhoid fever is conveyed by ice, because while ice is almost universally used in that city its death-rate from typhoid fever has always been and now is exceptionally low for an American city. Boston, on the other hand, while having (as New York also has) an excellent water supply, is supplied with ice of great purity; and yet the death-rate from typhoid fever in Boston is considerably higher than in New York. Again, the cities of Lowell and

Lawrence have long been supplied chiefly with ice cut from the polluted and infected Merrimac (cf. pp. 207–212). Formerly, owing to polluted water supplies, both suffered severely from typhoid fever, though not, as might have been expected if ice were the cause, in July and August when ice is most used, but generally much later. With the introduction of purer water, the ice supply remaining the same, typhoid fever in both cities has fallen to the level of typhoid fever in other cities in Massachusetts having ice supplies of unquestioned purity.

It was from the consideration of facts like these that the author was led to undertake the investigation which is detailed in the paper by himself and Mr. Winslow, and to conclude that in actual everyday life ice as a vehicle of disease is probably less important than might be supposed if one had in view only the fact that pathogenic germs may live for a long time in ice. There appear to be fortunately, numerous "mitigating circumstances," numerous conditions, which serve to decrease the dangers of ice as a vehicle of disease. And if all the facts are known and kept in mind, the various contradictory phenomena, which at first seem hard to harmonize, may be satisfactorily explained.

Briefly stated, the more important facts appear to be the following: (1) While it is true that some individual bacteria survive exposure to freezing and even very low temperatures, such conditions are highly unfavorable to bacteria in general, even of the same kind, especially if the exposure be prolonged. Water does certainly tend to purify itself, and under ordinary and favorable circumstances does actually and extensively purify itself, during freezing. On the other hand, such purification, while great, is usually incomplete. (2) Out of a number of individual bacteria of any kind subjected to freezing a large proportion usually perish, especially if they continue to be exposed to the low temperature for two or three weeks, but a small proportion survive. (3) There is good reason to believe that the

efficiency of the survivors and their virulence is weakened both by their loss of numbers, and by freezing or by long exposure to low temperatures.

These facts taken together with those already mentioned above enable us to explain all, or nearly all, the phenomena in question. They also enable us to draw important conclusions concerning the dangers of the pollution of ice, and concerning ice supply and the public health.

§ 6. — *The Pollution of Ice*

Although from what has now been said it is clear that there is much truth in the popular opinion that water purifies itself in freezing, it is equally plain that too much reliance must not be placed upon this process. Ice should be made only from good raw materials, *i.e.* from waters which are pure and potable; and this is doubly true if "artificial" rather than "natural" ice is to be used for public or private supplies. The processes of harvesting natural ice, and of delivering it to the consumer, still leave much to be desired. The use of horses whose droppings fall on the ice during the "ploughing" or cutting of the ice fields; the uncleanly habits of the workmen employed; the floating of the blocks through less pure, or actually polluted water, on their way to the ice-house; their storage, often in a packing of old and dirty hay or sawdust; and their final delivery into family, club or hotel refrigerators by common workmen after only hasty brushing with some ancient cloth or broom, — these conditions illustrate the need of improvement. Fortunately, however, ice in summer is usually bathed superficially in water from its own melting and thus roughly cleansed, so that grave danger from the sources mentioned is probably relatively rare.

In warm countries artificial ice is much used, and as processes of manufacture improve, it is likely to be more and more used everywhere. The author is strongly of the opin-

ion that, generally speaking, such ice is likely to be inferior to the best natural ice. It is liable to be made from impure water; when so made it has far less chance to purify itself by freezing; and, worst of all, it is promptly consumed; so that storage and the destruction of any microbes, which it may contain, by exposure for a long time to unfavorable conditions are not likely to occur. It is worthy of note that precisely as old (or stored) water is preferable to new, so also is old (or stored) ice. (*Cf.* pp. 237, 249.)

§ 7.—*Recapitulation*

From what has now been said we may derive the following inferences and conclusions: there appears to be good ground for the popular belief that natural ice considerably purifies itself in freezing. The ideal and most favorable condition is that offered by a lake of pure, quiet and deep water in a region remote from human habitation. In such a case, on a still, cold night, the surface of the lake chilled by the freezing air hardens into a thin and delicate mirror composed at first of shooting, interlacing crystals. Each of these, as it forms on the very surface of a mother-liquor which is itself almost wholly pure, readily pushes aside most foreign substances such as bacteria, though between the shafts of neighboring crystals or on their surfaces a few may be caught and confined. A little later, the first horizontal skimming of ice having been formed by the interlocking or other union of crystals, fresh crystals send shafts downward into the now more quiet water just beneath them, and, the cold continuing, join themselves firmly to the layer already formed. But now quiet reigns below the ice, and gravity incessantly drags downward through the water everything within its reach. The purest layer of water, therefore, is now the highest, and into this fresh crops of crystals are steadily growing from above. Thus it happens that the uppermost layer of the ice is least pure, for this

includes more of the dust of the air, more floating matters, and is formed without any overlying sheltering solid layer such as, after its formation, stills the water and shields the under layers. This ideal condition, however, is rarely found. An impure pond or river is too often the source of supply. A sudden freeze often follows a thaw which has made turbid and dirty the waters from which the ice is then derived; or a snow falling during a dry and windy period collects from the air a vast amount of dirt and falls upon pure ice, finally thawing and then freezing, only to weld itself as poor and porous "snow ice" to the better, purer ice beneath it.

Still, when all has been said that can be said against ice as a vehicle of disease, and while it cannot be denied that ice may at any time under suitable conditions readily serve as such a vehicle, it nevertheless remains true that water certainly strongly tends to purify itself in freezing, and that no considerable amount of disease has ever been satisfactorily traced to ice either as source or vehicle. As a vehicle of disease, ice is plainly far less dangerous to the public health than is either water or milk.[1]

[1] For an interesting discussion of the subject of "Ice Supply and the Public Health," see *Journal of the Massachusetts Association of Boards of Health*, XI. 4 (December, 1901), pp. 123–143. Also, H. W. Hill, M.D., "An Investigation of the Boston Ice Supply," *Boston Medical and Surgical Journal*, November, 21, 1901.

CHAPTER XI

ON MILK AS A VEHICLE OF INFECTIOUS DISEASE. THE POLLUTION AND INFECTION OF MILK. MILK SUPPLY AND THE PUBLIC HEALTH

§ 1.—*Milk as Food for Microbes and Mankind*

AMONG all the vehicles of infectious disease there is perhaps none more dangerous than milk. This fact is the more remarkable because milk has always been one of the most trusted of human foods. Clothed in a veil of white; associated with the innocence of infancy; of high repute for easy digestibility; believed to represent in perfection a natural dietary, popular and cheap,—milk has always deservedly held a high place in public esteem. Of late years, however, while maintaining its reputation in respect to cheapness, food value, blandness and digestibility, it has, in the eyes of physicians and sanitarians at least, come to be regarded, while in the uncooked condition, with general suspicion. The principal reason for this change of opinion is to be found in the fact that numerous epidemics of infectious disease have been traced with more or less of certainty to milk supplies; while the development of the modern science of bacteriology has tended to show that milk is a peculiarly favorable culture-medium for many species of bacteria, and may be therefore justly suspected of serving as a dangerous vehicle for the germs of infectious disease. It is doubtful, to say the least, whether any disease germs, under ordinary circumstances, ever really multiply in a fairly good drinking water, even when sewage-polluted, owing to the lack of a favorable environment;

but the very qualities which make milk a good food for mankind tend to make it likewise a good food for microbes, and there is only too much reason to believe that under certain circumstances some disease germs may not only survive, but even multiply, in fresh, pure milk, especially if it be kept warm.

§ 2.—*Origin of the Modern Distrust of Uncooked Milk*

For the reasons given in the preceding paragraph, there is to-day among physicians and sanitarians a widespread distrust of uncooked milk, and it must be admitted that the more the subject of milk supply in relation to the public health is investigated, the more cause there appears to be for uneasiness. Moreover, the conditions under which cows are kept, and the opportunities which exist for the pollution of milk, tend to confirm rather than remove this distrust. Aside from the fact, which would be regarded as highly peculiar if it were not so familiar, that milk is drawn directly from the body of an animal and therefore occupies an unique position among all human foods except that of infants, there remains the obvious circumstance that the milk supply constitutes one of the oldest industries known to man. There is every reason also to believe that it is not only old, but old-fashioned.

It is of recent years only that milk supply has come to be regarded as of importance to the public health. Previous to 1881 it was not generally known that milk is one of the readiest vehicles of infectious disease. It is said that the first epidemic of typhoid fever traced to milk was one in 1857, studied by Dr. Michael Taylor. In 1867 the same epidemiologist showed that scarlet fever might be distributed in a similar way, and simultaneously Professor Oswald Bell arrived at the same conclusion through his investigation of an outbreak of that disease. In 1877 an epidemic of diphtheria was traced to a milk supply. These and other cases which had been reported were brought

together in 1881 by Mr. Ernest Hart, and laid before the International Medical Congress of that year in a striking paper, which at once drew universal attention to milk supply as a vehicle of infectious disease. Mr. Hart in his paper gave the history of fifty epidemics of typhoid fever, which up to that time had been charged to infected milk, besides fifteen epidemics of scarlet fever, and four of diphtheria. "The record," says the eminent medical writer from whom these statements are taken, "since 1881 has not been less striking; indeed, since the method of investigating these occurrences has been more generally understood, milk has been constantly and justly incriminated as a cause of zymotic disease in man."

§ 3.— *The Fermentations of Milk*

If the year 1881 was important to the milk-supply industry and the public health for the reasons just mentioned, it was no less so for another and very different reason. It will be remembered that it was in this year that Koch's method of solid cultures for bacteria was introduced (see p. 53), and this method soon made it easy to investigate with some accuracy the ordinary fermentations of milk by observing the numerical increase of its bacterial ferments and their variety, while also studying their progressive effects upon the milk itself. The same method, which in other fields led to the discovery and elaborate study of the special ferments or germs of certain infectious diseases, such as typhoid fever, Asiatic cholera and diphtheria, made possible also the study of the behavior of these germs in milk, with the result that evidence was quickly obtained proving that under certain circumstances, milk offered to them an admirable culture-medium.

Further investigations along these lines have shown that city milk is often in an advanced stage of decomposition, and therefore far removed from the normal milk which is

drawn by the infant from the mammary gland of the mother. It has long been known that bottle-fed babies in cities show a much heavier mortality than those fed normally; and investigations appear to have proved that this is due, in part at least, to the unsatisfactory condition of city milk supplies. It is now well known that city milk is not only often falsified, but also frequently filthy, stale and half fermented. Moreover, the facts that tuberculosis is the cause of death of a larger number of persons than die of any other disease, and that tuberculosis is known to be common in cows, have naturally led many to suppose that numerous cases of this disease are due to the consumption of milk. More recently, also, it has been alleged on good authority that the mixed milk of a number of cows is seldom free from pus.

§ 4.—*Normal* versus *Fermented Milk*

By "normal" milk is meant milk as it flows from the teat of a healthy and well-fed mammal. Such milk is, as a rule, free from putrefactive bacteria. (Cf. § 7.)

Almost immediately, however, normal milk is invaded by a host of such bacteria, which find their way into it from the air, the dust of the stable, the cheesy remains of previous milkings in the angles of the pails and other appliances, the hide of the cow, or the hat or hands of the milker. It is held, also, that normal milk may be seeded with bacteria even before leaving the teat, the so-called "foremilk" having been found by numerous observers to contain a considerable number of bacteria, which are supposed to have come from infection, from without, of the milk in the main duct of the teat. However this may be, there is no question that normal milk is relatively free from bacteria, and fresh or unfermented.

It is worth while to observe, in passing, that normal milk, under natural conditions, arrives in the stomach of the

suckling almost instantly after leaving the teat; for, as we shall show, milk as obtained in cities and from public supplies in general is very different in this respect. City milk is always more or less old and fermented, more or less stale and more or less dirty. Between the time of its leaving the teat and its arrival in the stomach of the bottle-fed city infant, cow's milk has too often travelled over a long distance; too often undergone damaging exposure to dirt and air; and too often suffered extensive fermentation or decomposition. It is impossible to avoid the conclusion that it is, for these reasons, comparatively abnormal.

§ 5.—*Infantile Diarrhœa and Cholera Infantum*

Various observers have attributed to unsound milk, not only the high death-rate of bottle-fed infants in cities, but also certain special diseases, such as the infantile diarrhœa of summer and cholera infantum. There is reason to believe that in many instances, at least, unsound milk has much to do with these disorders, and in support of this view it is urged that the substitution of cooked (Pasteurized or sterilized) milk, for uncooked or raw milk swarming with bacteria, does away in a large measure with the troubles referred to. It is perhaps still too early to speak with accuracy on this subject, but the tendency certainly is, among those who have looked into the matter, to consider unsound milk as the source of many of the most serious troubles of infancy. Experiments conducted in hospitals and nurseries seem amply to justify this conclusion, and the supreme importance of a sanitary milk supply for such establishments is now generally conceded.

§ 6.—*The Pollution of Ordinary Milk*

Bacteriologic and microscopic examinations reveal the fact that ordinary city milk is highly polluted. Numerous observers all over the world have reported the presence in

ordinary city milk of vast numbers of bacteria; and inquiry as to the source of these micro-organisms has led to the discovery that milk is too often polluted, to a serious degree, by the dust of the air, the dung of the stable, and the uncleanness of pails, cans and other milking utensils, such pollution being unfortunately hidden by the opacity of milk, and unsuspected because of the idea of purity usually associated with its color. The fact appears to be that the dairy industry is, as a rule, still in a very primitive condition.

The following realistic statement, made in the author's hearing by a member of a suburban Board of Health, describes a condition which was only too common in rural New England in the last quarter of the nineteenth century, and has not yet wholly disappeared.

"If we consider merely the matter of cleanliness and the prevention of filth in milking the cows and taking the product to market, we still have a very large and difficult question to deal with. No doubt Boards of Health can do something to improve cow stables, to secure better ventilation, and more cleanliness — they can do something; but from what I have seen myself (and I was brought up on a farm), I know that a large part of the filth which gets into the milk gets there in ways beyond the direct control of Boards of Health, for it gets there by the careless behavior of the milker.

"The day has gone by when a pretty milkmaid went, in clean, white apron and with shining milk pail, to milk the cow with the crumpled horn out among the buttercups of a dewy morning. Instead, some old fellow stumbles out of the house and to the barn, with the stump of a clay pipe in his mouth, and wearing overalls and boots saturated and covered with the filth acquired by a winter's use. When he reaches the barn he selects some recumbent cow, kicks her until she stands up, dripping and slimy, and as he is a little late and the milk will have hardly time to cool before the man who carries it to the city will come along, he does not stop to clean up behind the cow, but sitting down on a stool, proceeds to gather the milk and whatever else may fall into a pail which perhaps is clean and perhaps is not. Of such refinements as washing the udder of the cow or wiping her flanks, he has never heard. If he has, it is only to scoff. Then he strains the milk behind the cows. That is bad enough, but it is not all the story. Every one knows that in straining the milk the strainer becomes obstructed more

or less with dirt and filth, and when the milk does not run fast enough, he would be a rare milker who hesitated to scrape away a place with his fingers so that the milk might run more freely. Those who have seen certain fingers, as I have, know what that means." — E. IRVING SMITH. *Journal Massachusetts Association of Boards of Health*, II, 2, p. 33 (1892).

§ 7.—*Systems of Public Milk Supply.* (A) *Normal Milk Supplies*

The primitive, original and fundamental form of milk supply is that in which the mammal — cow, camel, elephant, goat, sheep, mare or man — suckles its young. In this case, the milk supplied by the parent passes almost instantaneously from the milk gland into the stomach of the young — without lapse of time, without exposure to air or vessels, without human handling, manipulation or falsification — precisely as nature has prepared it. The only possibility of fault to be found with it, from the sanitary standpoint, is the opportunity of damage from the parent, in case that parent is unhealthy or ill fed. If the parent is healthy and well fed, such milk deserves the name of *normal* milk. Normal cow's milk, then, may be defined as milk as it flows from the udder of a healthy and well-cared-for cow.

§ 8.—(B) *Country, or Domestic, Milk Supplies*

Next in complexity comes the private, or domestic, supply, in which a family obtains its milk from its own cow or cows. This is the system which prevails on ordinary farms and in small villages, and survives sometimes as a luxury of the wealthy, even in large cities. In this case the milk is no longer strictly normal. Between the producer (the cow) and the consumer (the individual who swallows the milk) have come in one or more middlemen, — the milker, the housewife, the housemaid, as may be. Moreover, the milk has been more or less *exposed* to air, — possibly dust-laden, and always carrying microscopic

germs of fermentation; to vessels, — pails, pans, strainers, — often richly seeded with similar microscopic organisms; and *time* has elapsed, longer or shorter, so that these organisms have caused the milk to "work" or ferment, slightly or extensively as the case may be. This in itself marks a departure, often trifling but always real, from the absolutely normal milk supply, such as calves and infants naturally enjoy. The sources of danger are here much increased, for it is no longer merely the question of having a healthy, well-fed parent; we have now also to consider a possible contamination by the milker, the housewife, or other "middleman," before the milk enters the stomach of the consumer, and also those natural alterations which milk undergoes after being seeded with the germs of fermentation, during the time which elapses between its exit from the teat of the cow and its entrance into the stomach. In well-regulated families, however, the risk of damage so resulting is, from a sanitary point of view, comparatively slight; and those are fortunate who may enjoy the privilege of possessing a milk supply of this simple, primitive kind.

Not by any means the least important fact in this domestic system of supply is the possibility of complete, personal acquaintance on the part of the consumer with the sources of his supply, and a consequent more or less extensive control over them. This, as we shall see, he almost unconditionally surrenders when he becomes an ordinary dweller in a great city.

§ 9.—(C) *Village or Suburban Milk Supplies*

As man comes to live in larger villages and towns, some families give up the keeping of cows and buy milk of their neighbors, who, in order to supply them, keep more cows. The personal acquaintance of the consumer with the exact sources of his supply diminishes, and his personal control

is somewhat relaxed, though he still keeps up a general knowledge and supervision, and may, if he chooses, know and do more about his milk supply at any time. But, as the neighbor who supplies him keeps more cows, and more men, and uses more cans, and needs more time to distribute his milk, each possible source of damage to the milk becomes more important and the departure from the normal is, necessarily, gradually and constantly greater.

§ 10.—(D) *City* (*Railroad*) *Milk Supplies*

Finally, as the city continues to grow larger, the milk farms are pushed farther and farther away, until a state of things is reached in which the farmer can no longer himself deliver milk to the consumer, even with the aid of fleetest horses. The railroad is called in, the contractor, or some similar middleman, appears, and the farmer now becomes merely the producer. But the consumer cannot send to the railroad for his milk, and so another carrier, with special wagons adapted to the purpose, passes to and fro between the railroad and the consumer. This person is known to the consumer as "his milkman"; but, as a rule, he is a very different kind of person from the farmer, the original type of "milkman." In this final form of milk supply the producer may have no idea whatever of the final destination of his milk; and the consumer, as a rule, neither knows nor cares where the milk which he buys comes from. The personal relation between consumer and producer is totally lost, and the middleman comes to hold the position of principal importance, as the only person in touch with all. These circumstances, and the very size of the system, tend to make it largely mechanical, and all connected with it merely subordinate parts in a great machine which, for good or ill, must work on incessantly.

With the rapid growth of cities and the development of railroad facilities, it is likely that something like the sys-

tem last described, and which now holds good only for the largest cities, will come to exist, to a greater or less extent, even in smaller communities, and it is well that these tendencies, which concern farmers, middlemen and consumers alike, should be carefully noted by the sanitarian.

Under this system the milk is often two days old, and therefore relatively stale and half fermented, before it is actually consumed. It also necessarily passes through many hands *en route*, and is therefore accessible to manipulation, adulteration and contamination.

§ 11.—*Milk Supply in Hot Countries*

In tropical countries the systems of public supply just described do not usually prevail, doubtless owing to the fact that ice is not ordinarily available, and even if it were, might be inadequate for the satisfactory preservation of the milk.

It is said that among the Arabs milk is either consumed absolutely fresh when drawn from the cow, or else is allowed to sour before it is used. In Naples, and many other cities in warm climates, cows or goats are driven through the streets, and milked by their owners before the doors, and in the presence of, the consumers. The herds of goats thus driven slowly through the streets of continental cities, led by a goat-herd playing on some simple musical instrument, are familiar sights to travellers. It is stated that the Chinese never drink either water or milk without first having boiled it.

In all these and other customs of mankind regarding milk supplies, the sanitarian can readily trace the results of human experience. Absolutely fresh milk, approaching as it does the normal condition, is almost everywhere a favorite food. If, however, owing to local conditions, such as density of population, climate or the nomadic habit, milk cannot be obtained absolutely fresh, it is, and should

be, either cooked or soured before it is used. By cookery, the germs of decomposition and infection are destroyed; by souring, acid is produced, which is similarly unfavorable to many germs of decomposition and infectious disease.

§ 12.—*Epidemics of Typhoid Fever in Massachusetts traced to Infected Milk Supplies*

Several extensive epidemics of typhoid fever in Massachusetts have been traced to infected milk supplies, and the same thing is true, generally speaking, all over the world. As the author is naturally most familiar with those epidemics which he has himself investigated, he has chosen for illustration examples drawn from his own experience.

§ 13.— *The Springfield Epidemic*[1]

In August, 1892, the State Board of Health of Massachusetts was informed by the local Board of Health of Springfield that an epidemic of typhoid fever had appeared in that city. Investigation showed that the cases were not, as might have been expected, among the poorer classes of the people, nor in the midst of unsanitary surroundings, but in a district well provided with sewers, by no means overcrowded, inhabited by a superior class of citizens dwelling for the most part in separate and detached houses of high grade, each house surrounded by a lawn or grass plot, and standing somewhat back from the street. The plumbing arrangements were unusually satisfactory, because the houses were new and their owners well-to-do.

Various theories prevailed among the people to account for the epidemic, but all of these were easily disproved except that which attributed the cause to an infected milk

[1] For the full report, illustrated by diagrams, see Twenty-fourth Annual Report State Board of Health of Massachusetts (for 1892), p. 715. Boston, 1893.

supply. Almost every one of the persons affected with the disease was shown to have swallowed milk supplied by a particular milkman, and patient inquiry eventually revealed the fact that the milk distributed by the milkman in question was derived from a farm, several miles from the city, upon which there had lately been a case of typhoid fever. The excreta of the patient had not, at least for a time, been satisfactorily disinfected, and in one or more of several ways had probably found access to the milk produced on the farm and sent to Springfield.

§ 14.—*The Somerville Epidemic*[1]

In the same year (1892) a small epidemic of typhoid fever appeared in a particular section of Somerville, Mass. Inquiry soon showed that all of the cases were supplied with milk by one milkman. This time no typhoid fever was discovered on the farms from which the milk was derived, but it was finally disclosed that a son of the milkman, whose duty it was to transfer the milk from the larger cans, in which it came from the farms by railroad to the city, to the little cans in which it was furnished to the consumers, and who in various ways came more or less in contact with the milk, had been himself, a little earlier, a sufferer from, and was finally a victim of, typhoid fever, and the probable source of the disease among his customers.

§ 15.—*The Cambridge Epidemic*

In August, 1896, a considerable epidemic of typhoid fever appeared in the city of Cambridge, Mass., and it soon became evident that it was due to infected milk. Subsequent investigation revealed the fact that here also, as in the Somerville case, no typhoid fever existed on the farms from which the milk was derived; but that among

[1] *Op. cit.*, footnote, p. 273.

the workmen who manipulated the milk in the milk-house of the local (Cambridge) dealer there existed two, and possibly three, mild, and at first unrecognized, cases of typhoid fever.

§ 16.—*Epidemics traced to Skimmed (Separated) Milk, and Creameries*

In August and September, 1894, a small epidemic of typhoid fever appeared in the city of Marlborough, Mass. Various "theories" of the cause of the outbreak were held or suggested, and the local newspapers contained numerous letters on the subject, some alleging that the water supply was infected, some that the sewers were to blame, and some that accumulations of filth, especially dump-heaps, were responsible. The localization of the cases, however, not only disproved these "theories," but also suggested milk as the probable cause.

It soon became evident, nevertheless, that none of the regular milkmen were involved, the cases apparently deriving their milk supplies from a variety of different sources. Eventually, however, it turned out that there existed within the city itself a creamery from which was despatched daily a wagon loaded with skimmed milk ("separator" milk), and that nearly all the cases of typhoid fever had been supplied with such skimmed milk either from this wagon or directly from the creamery itself. Further investigation showed that the driver of the skimmed-milk wagon was at the time of the inquiry living on the upper floor of the creamery, and just recovering from a severe attack of typhoid fever. This young man had not only been the driver of the wagon, but had also worked over the milk, transferring it, filling the cans, and otherwise making himself useful about the creamery. In the investigation of this case, which was made by the author on behalf of the State Board of Health of Massachusetts, aid was de-

rived from the report of Dr. Welply, then recently published, on an epidemic of typhoid fever traced by him to a creamery in Ireland, and disseminated by separator milk.[1] In this case milk from a farm belonging to a family suffering from typhoid fever was taken to a creamery, and appears there to have infected the whole mass of separated or skimmed milk, through which it was distributed to numerous other families.[2] In the reprint of Dr. Welply's papers "four other epidemics due to separated milk" are referred to.

§ 17.—*The Question of Tuberculosis in Milk*

Inasmuch as milk is one of the most universally trusted and widely employed of foods, while cows are known to suffer seriously from tuberculosis and this disease surpasses all other diseases as an agent of death in the human family, milk has naturally fallen under the gravest suspicion as a vehicle of tuberculosis. Satisfactory proof of any such complicity as is suspected is, however, exceedingly difficult to obtain. Owing to the fact that tuberculosis is commonly a disease of slow development, it is almost impossible to trace any particular case in the human family to any particular infection, and the very abundance of opportunities for infection makes it hard to prove that one, and only one, source existed. It is hard to resist the belief that if a cow is suffering from tuberculosis of the udder, her milk is tolerably certain to be infected. Nor is it necessary even to assume the presence of udder tuberculosis in order to admit the possible infection of milk. Cows affected with pulmonary tuberculosis may, and often

[1] Dr. J. J. Welply, "Creameries and Infectious Disease," *The Lancet*, April 21, 1894. See also, by the same author, "Creameries and Infectious Diseases," London, Ballière, Tindall and Cox, 1895.

[2] For a full account of the Marlborough epidemic, see report by the author in Twenty-sixth Annual Report State Board of Health of Massachusetts (for 1894), p. 765.

do, lick their own flanks or udders and those of other cows, and conceivably may readily leave there fresh germs of tuberculosis from their sputum, which germs, barely dried, may soon after fall, or be brushed during milking, into the milk pail.

As a matter of fact, germs apparently identical with those of tuberculosis have been detected by microscopical examination in the milk of cows in which no udder disease could be discovered by physical signs, and these may have got in in the way suggested. We may remark, in passing, that such examinations are not competent to determine whether the germs in question are alive or not. This point can only be determined by cultivations, or, better, by inoculation experiments.

The most instructive and valuable evidence that we have comes from inoculation experiments, in which a number of healthy susceptible animals (guinea-pigs are generally used) are selected, and divided at random into two groups. One group is kept, as a control, under conditions precisely similar to those of the other, except that its members are not inoculated. To the members of the other group are given subcutaneous injections of milk suspected to contain the bacilli of tuberculosis. In certain experiments of this kind the inoculated animals have actually perished after a time with tuberculosis, while the corresponding control animals have kept free from it. Such experiments certainly seem to prove beyond all question that milk may be a vehicle of tuberculosis. They do not, however, prove that bovine tuberculosis is as readily, if it be at all, communicable to human beings by milk; and we have experimental evidence that human tuberculosis is not readily, if ever, conveyed to cattle. The whole subject, in brief, requires further elucidation.

Reports of cases in which a family used the milk of a tuberculous cow and afterward suffered severely from tuberculosis, should be received with caution. They are

almost always open to the suspicion and the possibility of being examples of coincidence, rather than cause.

§ 18. — *Scarlet Fever and Diphtheria in Milk*

A number of epidemics of scarlet fever and diphtheria have been attributed to milk as a vehicle, but the number is small in comparison with those of typhoid fever traced to milk. Moreover, a careful review of the evidence in these cases is calculated to leave the student somewhat less well satisfied that milk was really in some of the instances the sole vehicle of the disease.

§ 19. — *The Protection of Milk Supplies from Pollution*

The milk-supply industry, as has been said above, is still to a great extent in a primitive condition. The ordinary dairy farmer, no matter how honest or well-meaning, often has not the smallest conception of the sanitary aspects of his art. It is exceedingly unfortunate that dirt in milk cannot readily be observed, and that the characteristic odor of milk masks to a great extent evidences of decomposition which might otherwise be plain. What is needed is a campaign of education among the farmers who produce milk, concerning, first, the simple protection of a readily putrescible fluid from pollution with dirt and other elements of decay; and, second, the sanitary protection of milk from infection. It is no doubt a difficult matter to make sure that the hands and the clothing of the milkers of cows shall be thoroughly clean; that the udder and teats shall be washed, or at least wiped thoroughly with a damp cloth, before the milking begins; that the tail of the cow shall not make even occasional excursions through the pail during the milking; that cows shall be, like horses, groomed and kept clean so that caked dung shall not cling to their flanks, to drop, with dandruff from their hides, into the pail; that pails and cans and strainers shall be sterilized with steam or scalding

water so thoroughly that yellowish cheesy matter alive with myriads of bacteria shall not fill their corners or cracks; but it is these simple items, indispensable to cleanness, which, carefully attended to, will not only improve the milk, from a sanitary point of view, but also prolong its "life" or keeping qualities, and thereby in the end richly reward the producer who is willing to "take pains." (*Cf.* note on p. 392.)

It should never be forgotten that if drinking water were to be drawn, as milk is, from the body of a cow standing in a stable, by the hands of workmen of questionable cleanness, and then stored and transported over long distances in imperfectly cleaned, closed cans; being further manipulated more or less, and finally left at the door at an uncertain hour of the day, few would care to drink it, because its pollution and staleness would be obvious. It is clear, moreover, that milk requires, and deserves, even more careful treatment than water, for it is more valuable, more trusted and more readily falsified or decomposed. Nevertheless, until very lately, milk while legally protected from dilution by water has received little or no attention from boards of health on the simple question of pollution. It is cheering to observe, therefore, that steps are at last being taken even in this direction.

§ 20. — *The Protection of Public Milk Supplies from Infection*

It will be convenient and natural to divide this subject into two; namely, (*a*) protection from infection by man, and (*b*) protection from infection by the cow.

(*a*) The occurrence of numerous epidemics, in which it appeared that some person or persons working over the milk had infected it, has led to rules and regulations — often having the force of laws — governing the conduct of dairies by persons known to be diseased, or otherwise aim-

ing to protect the public health. To a brief consideration of these we shall come in the next section. Here we shall simply seek to develop the principles which should underlie such rules and regulations by considering in detail how, precisely, cows' milk may become infected from sources other than the cow, and especially through human beings.

Milk may become infected almost as soon as it is drawn from the cow by germs derived from the hands of the milker or from his clothing. If, for example, a milkman or milkmaid happens to be in the early stages of some infectious disease such as typhoid fever, cholera, scarlet fever, or diphtheria, and is not personally very cleanly, fresh infectious materials (fæcal, epidermal or mucous) may easily obtain access to hands or fingers, and in the process of milking be readily communicated to the milk. It is unfortunately a not unknown practice among milkers, in America at least, in order to soften and clean the sometimes dry and dusty teats of the cow, to begin by milking first with one hand and then with the other into the palm of the free hand held as a cup, and with the milk so drawn to bathe and soften the several teats before formally beginning to milk into the milk pail. In this case the hands often still drip milk for a moment or two directly into the pail, and the opportunity to transfer infectious matters from the hands of the milker into the warm, fresh milk, which is a good culture medium for many bacteria, is manifest. Clearly, no person affected with transmissible disease should be allowed to act as a milker, for even when no such moistening of the teats with milk as has been described occurs, the mere pressure of hands upon teats, which is a necessary part of the process of milking, may suffice to detach portions of infectious material, possibly merely microscopic in size, and cause them to fall into the milk pail.

In practice, however, this problem is a very difficult one, because it is often nearly or quite impossible to detect the presence of an infectious disease in its earliest stages. In

typhoid fever, for example, it may be a week or even a fortnight before the disease declares itself in an unmistakable manner; and it is admitted that persons very frequently have this disease not only in a form so mild that some never take to their beds (ambulatory or "walking" cases), but that they never even suspect that they have so serious a disease. It is plain, therefore, that legislation, even when honestly and faithfully obeyed, is not enough. Too often its application would resemble the locking of the stable door after the horse had been stolen. There is, indeed, only one absolute safeguard against the dangers of infection from diseased milkmen, and that is the most absolute and scrupulous cleanness, not only personal but, so to speak, professional also. The milkers should be thoroughly clean, and the operation of milking should be conducted almost as a surgical operation is, namely, with extreme cleanliness and constant dread of disaster from infection.

What has been said of the possibilities of infection of milk by the milker is no less true of all manipulation or "handling" of milk. If at any time milk is exposed to infectious matters from the hands of persons working over it, or to infected dust or epidermal scales from the clothing of such persons, danger exists. Several epidemics of typhoid fever have been traced by the author to persons manipulating or handling milk between the producer and the consumer. Those who desire to do so may pursue this subject in detail in the published reports of these cases.[1] It is probable that diphtheria and scarlet fever are more or less readily conveyed in the same way. If the infectious materials of the latter disease, as seems likely, can be conveyed in the epidermal scales during the "peeling" (desquamation) period, it is easy to realize how readily they may find access to milk either from the skin of the patient or the clothing of a friend of the patient. As regards

[1] See references above to Springfield, Somerville, and Marlborough epidemics.

diphtheria, the wonder is not that it appears to be sometimes conveyed by milk, but that more cases have not been traced to this source.

One of the most objectionable practices on the part of milk dealers in Boston is the custom, which is rarely if ever departed from, of *tasting* every large can of milk on its arrival in the city This is done to detect sour milk and enable the buyer (or middleman) to protect himself against the purchase of stale or ill-flavored milk. The "tasting" consists in removing the plug, applying the lips to the can, and taking into the mouth, as if for drinking, a small quantity of milk which is usually not swallowed but spat out again, generally upon the floor near by. Aside from the æsthetic considerations involved, it is apparent that the application to a mass of milk of lips perhaps associated with a throat charged with the germs of diphtheria is a most unsanitary procedure, and one that ought to be strictly forbidden. It is the appreciation of facts like the foregoing that has led to the establishment here and there of model dairies in which all possible precautions are taken to secure cleanliness and security against disease among both the workmen and cows composing the herd. To a brief account of these we shall presently return.

(*b*) We may now briefly consider the principles which should govern sanitary endeavor to secure protection of the public health against milk infected by the cow herself. It is obvious that, inasmuch as milk is for the most part consumed uncooked and comparatively fresh, the opportunity for direct transfer of infection from cow to consumer is easy, and therefore that, generally speaking, diseased cows should not be used as sources of milk supply On the other hand, it does not follow that a cow having a somewhat diseased liver, kidney, or eye, may not give normal milk; and in practice it is by no means easy, at times, to decide whether a cow is diseased at all, or, if so, to what extent; or, finally, whether being herself probably some-

what diseased, either temporarily or permanently, her milk is now, or is likely to be, affected. The matter is further complicated by the fact that the cow is a piece of property having a value to her owner, who naturally objects to her destruction or disqualification, and accordingly gives their fullest possible value to all doubts which exist as to the damage she may do. Moreover, veterinary medical science is not so advanced as to be in all cases thoroughly trustworthy in diagnosis, so that the whole subject is in a very unsatisfactory condition.

All parties interested agree that cows showing plainly and obviously the physical signs of advanced disease, of any serious sort whatever, should not be used for milk supply. It is only the diseases most difficult to diagnose with certainty, and especially tuberculosis, about which there is much serious contention. Even in this case, where the physical signs are pronounced and apparently unmistakable, there is as a rule no serious difficulty in securing the exclusion of the affected animals from the herd of milch cows. It is chiefly concerning the more obscure and early cases that grave controversy arises, and this has reached an acute stage only since the discovery of tuberculin by Koch, and its recommendation by him (and more recently by others) as an almost infallible diagnostic agent for the detection of tuberculosis, followed by legislative enactments looking to the destruction of cattle and cows condemned by the results of tuberculin tests. Tuberculin appears to be a valuable reagent for the detection of this disease, but it is urged with some force that it is not infallible; that it is so delicate as to detect sometimes trifling lesions, perhaps in places where they would be very unlikely to do harm or so limited as to be readily recovered from or checked; and that it damages normal, healthy cows by subjecting their tissues to a violent poison, if only for a time. For these and other reasons the owners of cattle in Massachusetts organized

and secured the repeal of a statute involving a compulsory tuberculin test, and seriously interfered with the work of the State Cattle Commission. This is perhaps not surprising when we reflect that proof of the complicity of milk in the causation of tuberculosis is not very clear (see p. 277); and that it is not certain that tuberculosis of inner organs, such as may cause reaction under tuberculin, and yet is not revealed by physical signs, can affect the milk unfavorably. Further experience with tuberculin may serve to show whether the original legislation or its hasty repeal was in this case the wiser.

It is not known or generally believed that typhoid fever can be communicated by the cow herself, either as a victim of that disease or as having drunk water infected with its germs. It is a question often asked during an epidemic of typhoid fever charged to milk, Can a cow that has drunk sewage-polluted water transmit the germs through her milk? The answer is that, so far as is known, she cannot and does not.

One of the most startling discoveries recently made in regard to infectious materials in milk is that of Dr. Stokes and an associate, of Baltimore, who investigated a curious creamy yellowish layer, of a slightly suspicious appearance, upon milk derived from a dairy tributary to that city. They found that the yellow layer was largely composed of *pus*, and finally traced its origin to a herd affected with garget. They even believed that they were able to trace the origin of the epidemic (which affected about eighty cows) to a milkman, who had probably brought in the germs from another state and by his hands conveyed the culture from cow to cow. The authors were led to investigate examples of mixed milk from other herds, and finally reached the important conclusion that the mixed milk from almost any herd usually contains more or less pus.

Scarlet fever possibly arising from cows suffering with that disease has already been dealt with (pp. 264, 278).

The conclusion of the whole matter is sufficiently obvious. The consumption of raw milk is always attended with grave dangers, partly from its usual pollution with dirt and dung, and the objectionable fermentations thus provoked, but chiefly from the fact that milk supply is an industry still in a primitive state, and that uncooked milk is liable to contain the germs of various infectious diseases derived either from the cow or from those persons who "handle" the milk.

The remedies lie along the path of progress. Very much as modern sanitary or aseptic surgery differs from that which prevailed before the time of Pasteur and Lister, so the sanitary or aseptic milk-supply industry of the future will differ from that of to-day; and precisely as successful sanitary surgery depends in the last analysis upon absolute cleanness, so also does the solution of the problem of successful sanitary milk supply.

§ 21.—*Safeguards against Polluted and Infected Milk*

As long as milk is consumed raw or uncooked, there will always be danger in its use. There is no possible way in which the absolute purity of raw milk can ever be proved or even established. The most that can be done with raw milk is to reduce the dangers of pollution and infection to their lowest terms; but after all possible precautions have been taken in regard to the health of the cow and in regard to cleanness in the utensils employed and on the part of those who "handle" the milk, mistakes may be made or accidents may happen by which the milk shall be polluted or infected. It may be best in certain cases to take the risks involved and to use raw milk for infants or invalids. There is some important evidence pointing in this direction; but after making every allowance for such cases, it still remains true that, from the standpoint of sanitary science, raw, uncooked milk is an unsafe food, and that

whenever it is possible it should, before it is swallowed, be cooked or otherwise treated so as to destroy any disease germs it may contain. Various methods have been proposed or employed to this end, and to a brief consideration of the principles involved in these we may now pass.

§ 22. — *Sterilization*

This process has long had its prototype in domestic practice in the custom of "scalding" milk, and the experience of generations has shown that repeated "scaldings" suffice to make milk "keep" a long time. Bacteriology has shown the reason why, which is simply that the ferments or bacteria which swarm in milk soon cause it to sour unless they can be killed, by heating or otherwise, or hindered in their activities by cold. The scalding process as conducted by the housewife has to be repeated in order to save the milk because, once milk cools down after boiling, fresh bacteria, falling into it from the air or obtaining access to it from pans or dishes not absolutely germ free, and finding the field clear, soon grow and multiply enormously, tending to bring about again very soon the former condition of a rich bacterial vegetation in a highly favorable soil or medium. The art of sterilization is based on the same principles, but avoids the necessity of repeated scaldings by careful prevention of fresh invasions after the original bacterial population has been destroyed.

There is no question as to the efficiency of sterilization of milk by thorough boiling or scalding, so far as the destruction of germ life goes, but the process possesses certain important disadvantages. In the first place, owing to the high temperature used and the time required, various chemical changes are wrought by which a peculiar flavor or "taste" is produced, known as a "cooked" taste, and this taste is disliked by many persons who enjoy the bland and characteristic flavor of raw milk. In the second place, there is evi-

dence which cannot be disregarded that thoroughly cooked or sterilized milk is not as readily digested by some infants as is normal or even so-called "fresh" city milk. Considerations of this sort have led to attempts to avoid prolonged heating at a high temperature by the processes of "evaporation," "pasteurizing," condensing by cold, etc., to which we shall briefly refer in the following paragraphs. For the sanitarian, however, the objections noted, while real and well worth avoiding, do not materially affect the great fact that sterilization of milk is an important sanitary safeguard. Because many dislike the taste of, and some do not thrive well when fed upon, sterilized milk, it is none the less true that by the use of sterilized milk infectious diseases, so far as these are conveyed by raw milk, can be altogether avoided.

§ 23.—*Pasteurization*

In view of the objections to scalded and sterilized milk which interfere with its practical usefulness by diminishing its popularity among adults and its usefulness for infants, various attempts have been made to destroy the germs, and especially any pathogenic or disease-producing germs it may contain, while yet preserving as much as possible its normal flavor and its digestibility. The most important of these attempts is that known as the process of "pasteurizing," so called in honor of Pasteur. Pasteurizing consists in heating any fluid (milk, cream, wort, etc.) to such a temperature as has been described. In the case of milk the temperature preferred is about 158° to 160° F., and it is claimed that this temperature maintained for twenty to thirty minutes suffices to kill all disease germs and most germs of fermentation in milk, and yet produces but slight changes in its flavor or digestibility. On the other hand, it is claimed by many that its taste is in fact somewhat altered and its digestibility impaired, though certainly to a less extent than when more heat is used. The author some

years ago stated his position in regard to pasteurized milk as follows, and still holds essentially the same views: —

"Most of the milk sold in Boston is at least twenty-four hours old when it reaches the consumer. Much of it comes by rail from distant parts of Massachusetts, and even from other states. The consumer is, as a rule, totally ignorant of the place of origin of the milk which he buys, and equally so of the conditions — whether wholesome or unwholesome, sanitary or unsanitary — of the farms on which the milk is produced.

"It would be of great advantage to consumers and producers alike if the milk farms tributary to a great city could be visited and inspected; and it would add materially to the keeping qualities of milk (and therefore to its economic value) if it could be carefully pasteurized before beginning its journey to the city.

"Moreover, inasmuch as typhoid fever is often disseminated by milk and as there is reason to believe that milk is a vehicle for some other infectious diseases, such as tuberculosis and possibly scarlet fever and diphtheria, pasteurization, which is a safeguard against the conveyance of such diseases by milk, commends itself to every sanitarian.

"Pasteurization also postpones the decomposition of milk and its consequent staleness by destroying germs which produce souring, and thus helps to keep it in this respect nearer to the 'normal' required by infants."

§ 24. — *Condensation*

The condensing of milk when it is effected by prolonged boiling under atmospheric pressure is a great, and probably an absolute, safeguard against infectious diseases conveyed by milk. Such "condensed" milk is, however, open to the same objections as sterilized milk, and probably in even greater degree. Condensed milk is, however, safe to use so far as infectious diseases are concerned; and in spite of the objections urged against, and which certainly require it to be used intelligently, it is a valuable adjunct to the sanitary food supplies of mankind. When milk is condensed at a lower temperature by the aid of the vacuum pan, as is often the case, it is probable that the product is almost if not quite equally safe from a sanitary standpoint, and somewhat less objectionable from the purely hygienic point of

view. Such milk, less condensed, is sometimes known as "evaporated" milk, and is highly valued by some.

An ingenious process proposed for condensation is that in which cold instead of heat is used for condensing, the water being removed from the milk by freezing. In this process advantage is taken of the fact that water in freezing tends to crystallize pure, by allowing milk, from which the cream has been removed (separated or skimmed milk), to freeze over in shallow pans subjected to intense cold. The thin skimming of ice constantly forming at the surface is broken up by rakes, and fresh layers form; these are broken up in their turn, and so on, until the whole mass becomes a magma of ice crystals and unfrozen milk. The mass is then centrifugalized; and the milk, thus readily separated from the ice, is returned to the pans for further freezing. At last a condensation of sixty to eighty per cent is attained, and afterward to the thickened fluid cream is added in proper proportions, so that when diluted with two, three or four times its own volume of water, a product is said to be obtained closely resembling fresh milk, having no "cooked" odor, and keeping its digestibility unimpaired. This process has not yet been perfected, but it is certainly ingenious in principle.

§ 25.—*Modified Milk*

The so-called "modified" milk is important rather from the hygienic than the sanitary point of view, but yet deserves mention and commendation inasmuch as its fundamental requirement is clean, pure, sanitary or normal milk. This having been secured, the process of "modification" consists in so adding to, or subtracting from, its normal ingredients that it shall contain specified amounts of sugar, fat, salts, etc., such as may be desired for particular cases or ordered by physicians in their treatment of disease or other abnormal conditions.

In connection with establishments supplying "modified" milk, dairies of a superior order are not infrequently maintained, and to a brief consideration of sanitary dairies in general we may now proceed.

§ 26. — *Model (Sanitary) Dairies*

With the advancement of sanitary science and an appreciation of the sources of danger in the milk-supply industry, there have been established here and there dairies in which every possible endeavor is made to provide, for those willing to pay for it, milk as safe and as normal as it is possible to procure by the use of the most enlightened methods. One or more of these may generally be found near every large American city, and they are deserving of the highest commendation and the fullest support from sanitarians, because they fill an important place and do a most useful work, while at the same time they serve as living, and generally prosperous, examples of proper sanitary standards of practice in what is still far too commonly a primitive industry, primitively conducted.

§ 27. — *The Cows*

These, in model dairies, are carefully chosen and of good breeds. Care is taken to ascertain, as far as possible, that they are healthy and vigorous, not only by veterinary examinations when they are added to the herd, but by similar examinations regularly and often repeated.

§ 28. — *The Stable, etc.*

The stable is so arranged as to have abundant space, light, fresh air and quick and easy removal of urine and droppings. The bedding is kept clean and sweet, food and drink are ample and carefully chosen, the period of lactation is not unduly prolonged, the cows are groomed very

much as valuable horses are, they are protected to some extent from the irritation of insects, they are given space out of doors for exercise in winter, and pasturage, with good water in abundance and sufficient shade, in summer.

§ 29. — *The Milkers*

The milkers must be of a grade high enough to appreciate, at least in some degree, and to be willing cheerfully to coöperate in, the general sanitary plan. They must be willing to wash their hands before beginning to milk. They must in some cases be ready to wear, while milking, uniforms of white, clean cloth. They must be willing, before beginning to milk, to wash the cow's udder, if this is necessary, or to wipe it and the teats with a clean, damp cloth. They must be ready to decline to use pails, cans, strainers, etc., not strictly and scrupulously clean. Above all, they must be ready to refrain from "handling" the milk in any way, if need be, when in themselves or their families there is even a suspicion of any infectious disease, such as scarlet fever, diphtheria, typhoid fever or the like. These are high qualifications, but they are not too high. Persons working over and about milk should have qualifications similar to those of a trained nurse, namely, intelligence, faithfulness, readiness to obey orders, some technical skill and a high devotion to duty. Like the nurse, they should be always mindful of the fact that carelessness, unfaithfulness or disobedience on their part may result in the gravest disaster.

It follows, as a matter of course, that such service must be well paid. It follows, also, that for all the care specified, — and even more is required than is here set down, — for the careful owner and manager, the veterinary doctor, and their various aids and appliances, large sums must be paid. Hence, those who enjoy the benefits of such sanitary dairies must be prepared to share the burdens of their

support. Milk sold from model dairies commands, and deserves to command, a higher price than that from primitive establishments carelessly conducted. There is not the smallest doubt, however, that impure milk is dear at any price, precisely as are impure water, impure air and other foods or necessaries of life.

§ 30. — *The Outlook for Improved Milk Supplies*

There is a very general, encouraging and wholesome tendency on the part of the public to demand a better milk supply. Already there are many signs that the time has gone by when it will be considered sufficient for a board of health to secure protection of the public against fraud due to adulteration of milk with water, or falsification, of one sort or another. It is a curious commentary on the subject that in Massachusetts many of the official inspectors of milk are in no way connected with the boards of health in their respective cities or towns. This, wherever it exists, should be changed, so that the sanitary protection of milk shall be, where it belongs, in the hands of those charged with protection of the public health.

NOTE. Many valuable suggestions upon this subject may be found in a paper by R. A. Pearson, M.S., entitled "*Market Milk: a Plan for its Improvement.*" [Seventeenth Annual Report, Bureau of Animal Industry, (1900).]

CHAPTER XII

ON CERTAIN UNCOOKED FOODS (MEATS, OYSTERS, FRUITS, VEGETABLES, ETC.) AS VEHICLES OF INFECTIOUS DISEASE. THE SANITARY SIGNIFICANCE OF COOKERY

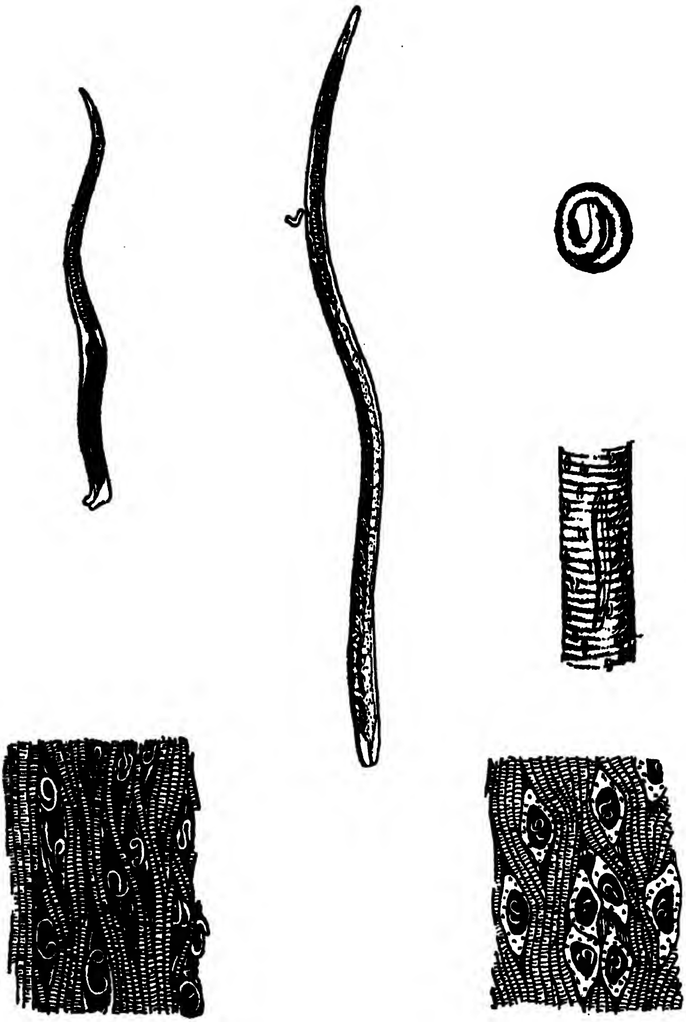
INFECTED water and infected milk are perhaps the commonest and the most dangerous vehicles of infectious disease. They are, however, by no means the only vehicles, certain other foods, such as uncooked meat, oysters and vegetables, serving readily enough as the carriers of infectious particles. The discovery of this fact was first made in the case of uncooked meat, the muscles of swine having been found in 1860 to have served as a vehicle of a parasitic worm, *Trichina spiralis*. Numerous epidemics of trichinosis have been studied since that time, and this disease is now well known to be caused by the consumption of the uncooked flesh of infected hogs. Special measures of prevention are now established in many countries against this disease, but the best preventive is the simplest, namely, thorough cooking of all such products — pork, ham, sausages and the like — as are derived from hogs.

§ 1. — *Trichinosis or the Pork-Worm Disease*

This disease, which is characterized by intense inflammation and irritation, with high fever, soreness, muscular paralysis, dropsical swellings and, in severe cases, death in from five to fifty days, is now known to be caused by a minute cylindrical worm barely visible to the naked eye, and therefore entitled to be called a micro-organism, which, in the larval state, inhabits the muscles of man, swine, dogs,

cats, rats, mice, rabbits and guinea-pigs, and many other animals, and in the mature state lives in the intestines of the same animals. The male is much smaller than the female, and when mature measures only about $\frac{1}{18}$ of an inch in length. The female is stouter and longer, measuring when mature about $\frac{1}{8}$ of an inch. The eggs are about $\frac{1}{1200}$ of an inch in length. The young trichinæ, like young tapeworms, occur embedded in the muscles of the hog and various other animals and man; but, unlike the young tapeworm, the young trichinæ are so small as to be quite invisible to the naked eye, and millions of them may exist in the flesh of a pig without producing any unusual appearance in the meat sufficient to attract the attention, unless with a microscope. When first introduced into pork or human flesh, the little worms are free and coiled up among the muscular fibres, but after four or five weeks they become enclosed in minute whitish, elongated oval or roundish cysts or capsules, due to the inflammation and irritation that they cause by feeding and living. After a year or more these cysts become calcified, and are then visible to the eye as minute specks scattered through the muscles. When enclosed in the cyst, the worms become dormant, and they may live for years, and even some time after the death of their host. They can do no further harm unless swallowed by man or some other animal. Each cyst contains a little slender worm about $\frac{1}{25}$ of an inch long, coiled up in two or three turns.

If pork or other flesh containing these worms — either free or enclosed in cysts — be eaten by man, they become liberated in the stomach, and, entering the intestine, attach themselves to its soft lining; and there, surrounded with abundant food, they grow very rapidly and become mature in about two days. Here the females live long enough to produce broods of from five hundred to one thousand young worms each. As one ounce of pork sometimes contains a quarter of a million or more of the worms, it is not surpris-



ing that the millions of adult worms and their offspring, sometimes resulting from a single meal of raw swine flesh, should by their presence produce great irritation and inflammation of the intestine and violent diarrhœa and vomiting, which are often the first symptoms in severe cases.

The young worms, almost as soon as they are born, begin to eat or force their way through the membranes of the intestine into the minute blood-vessels and other organisms, thus vastly increasing the irritation. Eventually they become diffused through the entire system, and are found most abundantly in the groups of muscles nearest the abdominal cavity.

The duration of the disease, like its severity, is in direct proportion to the number of living trichinæ swallowed, and varies from two weeks to three or four months. Even in many comparatively mild cases the suffering is intense, and the recovery slow and tedious. When all the worms have become lodged in the muscles and enclosed in cysts, the direct symptoms cease, and, if the strength of the patient has been kept up, recovery is probable.

Persons in robust health may be able to survive the attack of half a million or more of these flesh-worms, and recover; but there is a limit to all human endurance, and the numbers often contained in the muscles of man or the lower animals killed by them are almost incredible. In some very severe cases the numbers contained in human bodies have been estimated by reliable authorities to be as great as forty or sixty millions.

The cysts containing trichinæ were first observed in human muscles in 1822; but the worms from similar cysts were first named and described by Owen in 1835. They were, however, only regarded as anatomical curiosities of no practical importance until 1860, when Zenker proved that they are capable of producing the severe and often fatal disease now well known under the name of trichinosis, but which had been previously, as it probably often is still,

confounded with typhoid fever, inflammatory rheumatism, or rheumatic fever, poisoning and various other diseases.

§ 2.—*Infected Pork as a Vehicle of Trichinosis*

A few epidemics of trichinosis may be briefly referred to: at Hettstadt, in 1863, the flesh of one pig infected 135 persons, 20 of whom died. Many other similar epidemics have occurred in Germany. The following may be cited in the United States: at Marion, Ia., in 1866, a man named Bemis and eight members of his family ate underdone and raw ham, and were immediately taken sick. Three died, and the others narrowly escaped. Autopsy showed about 100,000 worms to a cubic inch of muscle in one of those who died. At Dubuque, Ia., two families were attacked. In one, five persons died; in the other, five or six. A case is cited by Dr. Horr in this connection in which the mother of a family ate of the central underdone part and took the disease, while those who ate the better cooked outside parts escaped. At Springfield, Mass., February, 1867, a man and his family ate of raw ham, and all seven members were attacked more or less severely according to the amount eaten. A daughter died, and the father had a long and very dangerous illness. At Albany, N. Y., in January, 1869, two boys ate of raw ham, and were infected. The rest of the family ate of the same ham cooked, and escaped. At Rome, N. Y., December, 1868, a man and his family, nine persons in all, ate raw smoked and dried sausages. The father, son and two daughters died before January 15. The sausages and salt pork were examined and found to be full of trichinæ, as were also the muscles of those who died. In New York City, January, 1869, eight cases occurred in a boarding-house from eating sausages. Two of the victims died in the New York Hospital, and others were dangerously sick. It is interesting to note that the physicians in two hospitals

mistook these cases at first for typhoid fever, and only discovered their mistake after one death had occurred.

The means of prevention in the case of trichinosis is very simple, namely, thorough cooking, and the rarity of the disease among people who avoid raw or underdone swine flesh in any of its varieties establishes the efficacy of the remedy.[1]

§ 3.—*The Question of Infection by Tuberculous Meat*

Of late years there has been widespread interest in the question of tuberculous meat. There is very little doubt that the germs of tuberculosis frequently occur in the muscles of cattle, cows, calves and other animals, and the possibility of their surviving the ordinary operations of cookery must be allowed unless these operations are thorough. In Germany, and to some extent in other countries, inspectors are employed to prevent the sale of meat obviously tuberculous. There are very few facts available, however, as to the precise dangers of such meat, and it is difficult to resist the belief that excepting in the use of underdone infected meat there is little danger of infection by tuberculosis from this source.

§ 4.—*Raw Oysters as a Vehicle of Infectious Disease*

The possibility of infection by raw oysters grown in sewage-polluted waters had been recognized by sanitarians, but not much emphasized, previous to 1894. In that year, however, the attention not only of sanitarians but of the whole world was drawn to the subject by a remarkable epidemic of typhoid fever among certain students of Wesleyan University, in Middletown, Connecticut, who had attended a college fraternity banquet on the 12th of October, and had there eaten raw oysters which were afterward

[1] § 1 and § 2 are summarized from a Report prepared by Professor A. E. Verrill of Yale University for the State Board of Agriculture of Connecticut.

proved to have been derived from sewage-polluted and probably typhoid-infected oyster-beds. A careful investigation was made at the time by Dr. H. W. Conn, Professor of Biology in Wesleyan University on behalf of the State Board of Health of Connecticut, whose report may be found in the Seventeenth Annual Report of the State Board of Health of Connecticut for 1894, and also as Appendix Number Three of the Supplement to the twenty-fourth Annual Report of the Medical Officer of the Local Government Board for 1894–1895, entitled "Oyster Culture in Relation to Disease," p. 152. London, 1896. This epidemic was so remarkable, so ably investigated by Professor Conn, and forms so complete a demonstration of the efficiency of raw oysters as vehicles of disease, that no apology need be made for giving a somewhat extended abstract of the original paper. The author says very truly: —

"A more typical example of an outbreak of typhoid due to a single source of infection has hardly been found in the history of medicine, and the example furnishes a demonstration of a new source of danger for this disease.

"The use of raw oysters has before been suggested as a possible source of the spread of the disease. The readiness with which these absorb water, and the fact that they not infrequently lie in positions where contamination with sewage appears to be possible, has led to their being suspected in several cases. It has hitherto, however, not been possible to trace any distinct epidemic to them with anything like demonstrative evidence. The conditions which have occurred at Wesleyan have, however, been exceptionally well adapted to point out this connection. Indeed, if one had planned beforehand a series of experiments designed to prove the possibility of oysters as distributing typhoid, it would hardly have been possible to have devised a more satisfactory series of conditions than those which have obtained in this outbreak at Wesleyan."

§ 5. — *An Epidemic of Typhoid Fever traced to Infected Oysters.*

About October 20, 1894, several students were seized with a mild form of sickness accompanied by slight fever,

which was not at first regarded as of much importance. The cases increased in number, some became more severe, and after about a week it became evident that a few, at least, were suffering from typical typhoid fever. New cases continued to appear until, by November 1, there were more than twenty. After November 1 the cases fell off, although one appeared as late as November 9. In all, there were twenty-five cases — twenty-three of well-defined typhoid, of which thirteen were very severe. Four of those attacked died.

Investigation was begun on November 4. Suspicion fell at first upon certain wells on the college campus, but these were excluded, chiefly on the ground that they were used by large numbers of townspeople as well as by college students, and that no typhoid had appeared among the townspeople.

No common bond was at first discovered among the victims of the disease, some of whom lived in different dormitories or club-houses, and others in private houses in the town. Nor did the persons affected board at the same tables. Besides, Wesleyan University is a coeducational institution, and it was early observed that the young women in the University — about fifty in number — were wholly exempt. Closer investigation showed that, with three exceptions, all the cases attacked belonged to three fraternities, and that within these some extremely potent source of infection had been active. Attention was thus concentrated upon these fraternities and their club-houses.

As is usual in such cases, the plumbing was carefully examined, and in two of the three houses it was found to be new and unexceptionable. Attention was next fixed upon the boarding clubs within the fraternities. The water, the ice and the milk were all considered, but excluded as sources of infection, from the fact that they were shared in common by other fraternities or by the townspeople. Similar circumstances excluded cream, ice-cream, butter, fruit,

and other articles as probable sources of the disease. So difficult and far-reaching was the inquiry, that it was even suggested that certain new foot-ball suits might have been infected, thus giving rise to the disease; but only a few of the men who had used the suits were found to be suffering from the disease, while several of the sick men had never touched them. There was also no evidence of secondary infection which could explain the outbreak, and particularly as there were no early cases of fever which could have served as the sources of such secondary cases. The first case appeared about October 20, and within a week from that time at least fifteen other cases had made their appearance.

These facts, of course, indicated plainly a common source of infection, and made it possible to believe that any of these was the source of all the others by ordinary contagion.

Moreover, there was a very small amount of typhoid in the city, and —

"In short, all the lines of investigation upon the relations of the students, the conditions of their fraternity houses, and the tables at the fraternity houses led to negative results, giving no point of common union between the three fraternities in question, which was not shared equally by the four other fraternities and the ladies in the college, and equally by the citizens in town."

A study of the dates on which the disease had appeared threw suspicion upon a series of fraternity suppers held at the society initiations of new members upon the 12th of October, and this suspicion was strengthened by the explanation which it appeared to offer of one of three cases which had appeared among members of the University not in any of the three fraternities. This person had attended the initiation banquet held by one of these three clubs, but had not boarded with them either before or afterward. Examination of the menu of the banquets excluded nearly all articles of food, such as water, ice, milk and cream, ice-cream, fruit and salad, as possible sources. The celery

used in the salad was at first regarded as a source of possible danger. It had been bought from different dealers, but these dealers obtained it all from the same grower, and he had occasionally washed his celery in the water of the Connecticut River — a somewhat suspicious circumstance. Further inquiry, however, showed that the same dealer supplied nearly all the celery used in Middletown, and had consequently furnished hundreds of families from the same source.

As a result of the closest inquiry in regard to every article of food or drink used at the banquet, there were found to be only three common to the three suppers; namely, ham, a small amount of fruit, and raw oysters. The ham was readily excluded, both because it had been cooked and because the same dealer supplied other fraternities. Moreover, there was no reason to suppose that it had been contaminated. The fruit had been shared by other fraternities and by townspeople, and was therefore excluded.

"As soon as attention was turned to the oysters, however, the problems began to be solved at once. To those engaged in the investigation, one of the most striking phenomena was the quickness with which the puzzling questions were answered as soon as they were studied in the light of the oysters as a possible source of contamination. It was found that the ladies in the college did not hold any special supper on the evening of October 12, nor eat raw oysters, either then or subsequently. It was found that of the other four fraternities, two did not use oysters at all at the initiation suppers; one obtained oysters from Hartford dealers, who obtained them from a different source than the Middletown dealers. The fourth used the oysters from the same source as the fraternities in question, but had used them cooked, while the three fraternities that had suffered from typhoid had eaten the oysters on the half-shell, and consequently raw. As soon as it was conceived that the oysters might be the cause of the trouble, one more of the exceptions above mentioned was explained, for one of the students belonging to another fraternity, who had suffered from a mild fever, stated that at about the time of the initiation banquets he had eaten raw oysters in the oyster dealer's store in town. This, of course, made it possible to bring this case within the same source of infection.

"Inquiry as to the use of the oysters in town revealed nothing which

relieved the oysters from blame. Quite a number of families were supplied from the same lot of oysters, but so far as could be learned, only one family bought them to eat raw, and this family had subsequently moved from town and had been lost track of. Further facts concerning this case will be mentioned later. The attendants in the oyster dealer's store had probably eaten of the raw oysters, inasmuch as they did frequently do so, although they had no definite recollection of this particular lot. Neither of them had experienced any evil results. This, of course, is not surprising, since ordinarily not much more than ten per cent of those exposed to typhoid fever suffer from the exposure; and even among the students at the banquet not quite one in four took the disease. If the people in town who ate the oysters had not generally cooked them before eating them, a larger number of cases would have been expected."

The oysters at the banquets were served on the half-shell as a course at the beginning of the supper. Careful inquiry was made as to how many persons had actually partaken of the oysters, and direct connection with the oysters was traced in all cases except one, this one student being unable to remember that he partook of them. He did, however, attend one of the banquets. The four who died were among those who partook of the oysters.

There were also present at the banquets a number of persons not students of the college. Among them were a number of alumni, and five students from Yale University. Reports were obtained from twenty-four of the alumni who ate of the oysters. Among them were several cases of slight illness, chills, diarrhœa, weakness, and the like which appeared at about the same time that the typhoid appeared in Middletown. These may or may not have had some connection with the infection. In addition, four cases of genuine typhoid fever appeared, most of which had been pronounced to be typhoid before there was any knowledge of connection with cases at Wesleyan University. None were severe, but all appeared simultaneously with the cases at Wesleyan.

Of the five Yale students who attended the banquet, two developed typhoid fever, though at a rather late date.

These facts demonstrated that the cause of the infection was to be sought in the initiation suppers. The cessation of new cases at the end of four weeks, and the appearance of at least six cases among visitors who came to the banquets and went away immediately afterward, —

"are sufficient in themselves to indicate beyond peradventure that the initiation suppers are to be regarded as the source of infection. And when, further, it is seen that only one article of food or drink was used in common by these three societies, that was not used equally by the other fraternities in college and by people in town in general, it becomes equally certain that this one article of food must have been the source of infection.

"Inquiry showed that the oysters in question had been taken from deeper water in Long Island Sound, and had been brought [to Fair Haven, Connecticut] into the mouth of a creek known as Quinnipiac River, and allowed to lie in fresh or brackish water a day or two for fattening before they were taken out of the water and sent to the consumers. During this period of fattening, the oysters are known to absorb fresh water and to swell up and become quite plump. The object of this treatment is partly to thus 'fatten' the oysters, and partly to wash them. Close to the oyster beds where this fattening occurs are the outlets of a number of private sewers. At a distance of some three hundred feet from the beds where the oysters were fattened was an outlet from a private sewer from a house in which were two cases of typhoid fever. The patients were a lady and her daughter. The cases were severe, the lady dying on the 21st of October, and the daughter convalescing only after five weeks' sickness. . . . The distance from the outlet of the sewer to the oyster ground was . . . between 250 and 300 feet. When the grounds were surveyed, it was further noticed that at the rising tide an eddy was found to be setting along the shore from the region of the sewer outlet up stream, in the direction of the oyster beds. This condition would plainly make it possible for typhoid contaminations from the sewer to be carried to the oysters.

"Examination as to the dates of the cases of typhoid occurring in the house on the sewer showed that the two persons in question were taken sick at just about the time that the oysters sent to Middletown were collected. The oysters were sent to Middletown on October 10, and the doctor was first called to these cases on October 11. The period of incubation of typhoid fever is known to be somewhat variable, and had certainly existed some time before the doctor was called.

From the fact that when the doctor was called the lady was suffering from a severe chill and fever, it was plain that the conditions were such that infection through the sewer might naturally have taken place at least for several days prior to the period of the first visit of the doctor; for during this incubation period the persons may appear well, and yet the presence of the typhoid germs render their excreta infectious. Indeed, the danger might be even greater at this stage than subsequently, since as soon as the disease is plainly indicated nurses will be pretty sure to disinfect the excreta and thus diminish the danger. This would bring the time of possibility of infection at just about the period when the oysters sent to Middletown were collected."

Special investigations made by Dr. Charles J. Foote, of the Yale Medical School, showed that typhoid bacilli forced in between the shells of oysters taken from the creek were found alive and capable of growth at the end of forty-eight hours, and —

"this is all that is required to account for the outbreak at Middletown."

In connection with an outbreak of typhoid fever at Amherst College at the same time as that of Wesleyan, it was learned that Fair Haven oysters had also been sent to Amherst. In the latter institution a similar banquet was held upon the same evening, October 12, at which raw oysters were served, and of six students who afterward suffered from typhoid fever all but one ate raw oysters on or about that date. It was not discovered whether or not the oysters came from the same dealer in Fair Haven, but the suspicion was strong that such was the fact.

One of the most interesting and instructive circumstances connected with this epidemic remains to be stated. A young man whose home was in Boston, himself a student at Harvard University, came down with typhoid fever. His case at first seemed utterly inexplicable. It happened that his father was a physician and for a time no reasonable explanation could even be thought of. It proved, however, that about two weeks before he fell ill he had gone home with a classmate whose family lived in Middletown,

and inquiry showed that he was attacked, after he had returned to his home in Boston, at precisely the same time as the Wesleyan students, and that he had eaten raw oysters while in Middletown. It further appeared that the oysters which he ate came from the same dealer as those with which the Wesleyan banquets were supplied, and that he had, in fact, partaken of the one lot which, as was mentioned above, had been sold by the Middletown dealer to a family in Middletown to be eaten raw.

§ 6.—*Dangers of Infection from Raw Shellfish*

Professor Conn's remarks upon this subject are instructive:—

"It is a very important point to determine to how great a danger the public is exposed from raw oysters. Is the distribution of typhoid by oysters a rare incident, or is it a constant and considerable danger? These questions are being everywhere asked. Upon this matter at present little can be given beyond personal opinion. But the question is such a vital one that a word of personal opinion here may perhaps be pardoned.

"In the first place it appears evident that the public opinion at first exaggerated the amount of the danger. The lot of oysters sent to Wesleyan was very thoroughly infected, but there is no good evidence as yet that other lots of oysters from the same place were equally dangerous. The oysters sent to Amherst were probably also infected, but these probably belonged to the same lot as those sent to Middletown. Beyond this it has as yet been impossible to trace with certainty other instances of typhoid to the Fair Haven oysters. If it were true that all the oysters fattened at the same place were similarly infected, it would be expected that quite a number of cases of the disease should be traceable to the oysters. In New Haven especially, where the Fair Haven oysters are used largely, there would presumably have been found an exceptionally large amount of typhoid. There has been some considerable typhoid in the city during the months of October and November, and in a few cases it has been presumably traced to oysters as shown elsewhere in the report of the State Board of Health. But there is hardly the amount that would be expected if the oysters were all subject to a contamination such as that which affected those sent to Middletown. Indeed, the consideration of the conditions at the oyster-

beds would lead to the belief that the contamination of the oysters would be exceptional. Where the oysters were placed near the mouth of a small sewer, and when this sewer came from a house containing typhoid patients, the danger of their contamination would be at its maximum. Should they chance to be placed near the mouth of a large city sewer, the danger, though a more constant one, would be much less likely to produce any considerable contamination of a large lot of oysters, since the typhoid material would be mixed with so much water as to distribute it widely and in a very dilute condition. Only an occasional oyster would thus be infected. At Fair Haven, however, when a proper eddy brought the material from the vicinity of the sewer toward the oysters, the chances were good for the whole lot to become infected. Perhaps oysters might lie in the same place many a time before and after, and not be injured thereby, because no eddy happened at the right moment to sweep typhoid material in their direction. The danger from typhoid infection is, therefore, probably somewhat exceptional, even under the conditions existing. Where the oysters are fattened at a distance from sewers, the danger practically disappears; and even where they are open to infection from large overflow of a city sewer, the danger is certainly less than in the fortunately exceptional case of the oysters in the vicinity of a private sewer containing typhoid excretions.

"The extent of the danger will plainly depend very largely upon the question whether the typhoid germs actually grow and multiply in the oyster, or whether they simply remain alive there for some time. It may be that the oysters furnish a good culture ground for the typhoid germs, which grow rapidly when once within the shell. This would, of course, greatly increase the danger, for one lot in a fattening bed might infect others. On the other hand, it may be that the germs do not grow in the oysters, but that only such individual bacteria as find entrance remain alive. In this case the infectious material would be found only in the juices in the shell and adhering to the outside of the shell. The danger would, of course, be much less. Which of these two conditions represents the facts cannot at present be stated. It is hoped that experiments now in progress will settle the matter. But, according to either view, oysters may serve as a means of transportation of typhoid wherever they are fattened in the vicinity of sewers; and wherever they are placed in the mouths of fresh-water streams for this fattening process, there will always be the chance of contamination from sewage. Few of the fresh-water streams in the vicinity of our large cities fail to have sewage emptying into them. While, then, we cannot determine the extent of the danger, and while, in the opinion of the writer, the danger is not very great, it must be recognized as a danger. Probably not a few of the obscure cases of typhoid which develop each fall shortly

after the oyster season opens, and which cannot be traced to any source, may be due to contamination through oysters. It is, of course, impossible to determine the truth of this suggestion; but now that the possibility has been pointed out, we may hope that our health boards may, in future years, be able to determine the real extent of the danger. One thing is sure: the public health is placed in jeopardy when oyster dealers, for the sake of producing plumpness, place oysters in the mouths of fresh-water creeks in close proximity to sewers. It is hoped that one result of the epidemic at Wesleyan will be to lead to greater care in this direction, both on the part of the oyster dealers themselves, whose business will certainly be greatly injured by the repetition of such outbreaks of typhoid as that at Wesleyan, and on the part of our boards of health, who have in their keeping so much of the public weal."

§ 7.—*English and French Opinion in Regard to Dangers of Infectious Disease from Raw Oysters*

Roused by the remarkable American epidemic which has just been described, the Local Government Board instituted a careful investigation of the conditions under which oysters and certain other mollusks are cultivated and stored in Great Britain; and a valuable report, bringing the whole subject up to date (1896), appeared as a supplement to the report of the medical officer of that Board for 1894–1895. This contains a report by Dr. H. T. Bulstrode on "The Conditions under which Oysters and Certain Other Edible Mollusks are cultivated and stored along the Coast of England and Wales"; a report by Dr. Klein on "Certain Bacteriological Researches," in connection with the same subject; a copy of Professor Conn's report, already quoted in the preceding paragraphs, as well as extracts from the "Proceedings of the Academy of Medicine of Paris relating to the Spread of Disease through the Agency of Oysters."

§ 8.—*The Contamination of Oyster-beds by Sewers*

The concluding remarks of Professor Conn, in his report on the "Epidemic of Typhoid Fever caused by

Raw Oysters at Wesleyan University," indicate, conclusively and in detail, the dangers to which oyster-beds are subjected when so placed as to be overflowed and contaminated by sewage. The English report referred to in the preceding paragraph furnishes numerous instances of the growing or storage of oysters under unsanitary conditions; and those charged with the conservation and promotion of the public health should keep in mind the possibility of such contamination, as well as the necessity for its prevention. No extensive investigation of this subject has as yet been made in the United States; but there is good reason to suspect that if such examination should be made, it would reveal, in many cases, the existence of unsanitary conditions in connection with the oyster industry.

One of the most interesting corollaries of the facts now in our possession in regard to the dissemination of typhoid fever by oysters is the explanation which it furnishes of certain so-called "sporadic cases" of typhoid fever hitherto inexplicable. Whether or not the same facts will suffice to account, in part, for that excess of typhoid fever which is characteristic of many American communities over similar communities in the Old World, is unknown; but it is difficult to resist the feeling that such may be, to some extent, the fact. The whole subject of the dissemination of disease through uncooked foods requires further study and elucidation.

§ 9. — *Fruits, Vegetables, Ice-cream, etc., as Vehicles of Infectious Disease*

Inasmuch as any uncooked food material may be polluted, and, if eaten in this condition, may become the source of disease, it is easy to see how berries, such as strawberries, grown and lying on earth which has been fertilized with night soil, or mulched with infected manure; raspberries, cherries, apples, grapes, and similar fruits;

vegetables, such as lettuce, celery, radishes, onions, water-cress and the like, if eaten raw, or without adequate cleaning, may readily convey the germs of infectious disease to the consumer. There can be little doubt that the common American practice of buying fruit at fruit-stands, or from passing venders on the streets or in railway trains, may be a ready means for the distribution of infectious disease. When we reflect that not infrequently the fruit shop is also, to a greater or less extent, the home of the vender's family; when we reflect on the frequent picking over of berries, cherries, apples, and the like, by persons whose hands and whose personal habits may be far from clean; when we add to this the exposure of the fruit to dust and dirt from various sources; and when, finally, we remember that buyers of such fruits or vegetables often devour them on the spot without stopping to make sure that they are clean, we can readily see that in such food materials thus exposed, and eaten without having been sterilized by cookery, we have a ready means for the dissemination of infectious disease and an explanation of "sporadic" cases.

On the other hand, it is reassuring to note that certain fruits, such as oranges and bananas, although usually eaten raw, are effectively protected by their skins, which are invariably rejected, leaving only the clean and sterile interior to be eaten.

As to sugared figs, dates, and similar preserved fruits, while there is probably less danger, it must not be overlooked that if these have been prepared by unclean or infected persons, they also may become vehicles of the germs of infectious disease.

The dangers connected with the consumption of ices and ice-creams are probably real. After making all possible allowance for those cases of ice-cream poisoning which may have been due to metallic poisons derived from the freezer or other utensils, it must be admitted that the ice, the water, and especially the milk, used are liable to be sources

of disease in ices or ice-creams. Bacteriological examinations of ice-cream are by no means reassuring, large numbers of germs often being present, and ices and ice-cream may conceivably do harm either by the bacteria which they contain or by their chemical products (toxines or ptomaines).

§ 10. — *The Sanitary Significance of Cookery*

Nothing is more certain in sanitary science than that cookery, which by the use of heat destroys parasites (including bacteria), is of the very highest hygienic value. If we may accept Charles Lamb's celebrated account of its discovery and general introduction, these were due more to the appetizing flavors which it develops than to anything else. To-day, however, the sanitarian recognizes that important as are the flavors developed by cooking in stimulating appetite and creating or arousing a keen relish for food, they are of but minor consequence as compared with the importance of freeing roast pig and similar foods from possible parasites such as *Trichina*, or tapeworms (p. 1[illegible]8). Writers on the physiology of cookery do not usually dwell sufficiently upon this aspect of the subject. They are accustomed, rather, to point to the greater digestibility of starches, meats, and fats when these are properly prepared for internal digestion by the external digestion (cookery) of the kitchen. They emphasize also the improved flavors developed, which arouse the appetite and stimulate the powers of digestion. These are unquestionably of great importance; but probably far more important in the history of the race has been the fact that by fire food is largely purified from living parasites and other agents of infection.

CHAPTER XIII

ON THE PREVENTION AND INHIBITION OF INFECTION, DECOMPOSITION AND DECAY. ASEPSIS AND ANTISEPSIS.

§ 1.—*Asepsis, or the Prevention of Infection by Exclusion*

It has already been stated in a previous chapter that for the genesis of infectious disease two factors at least are necessary; namely, first, an infectious substance, material or element, ordinarily a micro-organism; and, second, a susceptible subject. In other words, a state of infectious disease in an organism, whether plant or animal, depends upon an infectious element proceeding from the environment and also upon a special condition of the organism such that it is capable of being successfully acted upon or interfered with by the infectious element or its products. Infectious disease in its transmission or distribution thus represents one phase of the eternal struggle for existence, or that interplay with the environment which is the fundamental phenomenon of life (cf. p. 63). On the part of the organism attacked, it represents a phase in that continuous attempt at adjustment of internal to external relations which has been well defined as a leading characteristic of the life process (cf. p. 69). It will not do to assume that the cause of disease resides either in the infectious element alone or chiefly, or in the organism attacked alone or chiefly. The true cause of disease is to be found in the coöperation of both factors, namely, the infectious element and the susceptible organism. It cannot be denied, however, that in the common, everyday use of the word "cause," it is the aggressor rather than the defendant which is prop-

erly cited to appear; and nothing is clearer than the fact that if the infectious element can be successfully excluded or warded off, the disease, which might otherwise appear as the result of its entrance or attack, can be avoided.

Modern surgery is the best possible example of the beneficent results of this kind of procedure. Before any serious operation upon the internal portions of the organism is, to-day, undertaken the parts upon which the incision is to be made are carefully cleaned, and even sterilized, with the sole object of excluding putrefactive or morbific germs. All knives and other instruments, all ligatures and similar appliances, are carefully freed by heat or by disinfectants from possible septic, putrefactive or infectious elements, and the most extraordinary pains are taken to exclude as completely as possible all micro-organisms. Surgery of this kind is rightly called "aseptic," and although doubtless in many cases it is not absolutely successful in excluding every micro-organism, it is nevertheless sufficiently so in the great majority of cases to insure the wonderful success which attends modern surgical operations.

We have referred to aseptic surgery in an earlier chapter as "sanitary" surgery, and the justice of this appellation will be perceived when we point out that precisely the same kind of exclusion is sought for in the larger procedures of the public health, as when, for example, a water supply is freed from the germs of infectious disease by exclusion. When pains are taken to see to it that no cases of infectious disease shall be allowed to infect a particular watershed, we are acting upon principles precisely similar to those invoked in a modern "aseptic" surgical operation, and there can be no doubt that the procedure is at least as reasonable and as desirable in the case of the water supply, which affects thousands, as in the case of a single patient undergoing a surgical operation. The life of the community may, in theory at least, and to a large extent

in practice, be protected by the mere exclusion of pathogenic micro-organisms from water supplies, milk supplies and air supplies.

§ 2. — *Quarantine and Isolation*

It is the recognition of facts like these which have led even uncivilized peoples instinctively to the endeavor to ward off disease in a wholesale fashion by the exclusion of suspected persons, or by their detention at the frontier, of a particular country until time shall have demonstrated that they are or are not vehicles of infection. The word "quarantine" is in itself a witness to the custom of detention, which in former times was sometimes forty days. Modern sanitary science has tended to show that quarantine, or the attempt of communities to protect themselves by the exclusion of human beings and merchandise which are possible vehicles of infectious disease, is only a rude and generally imperfect method of exclusion. There can be no question, however, as to the legitimacy of the fundamental principle involved.

Of late years, and with the increasing evidence of the difficulty of securing freedom from infectious disease by exclusion, the practice of quarantine, at least in the old form and on the frontier, has fallen into comparative disrepute. A modified form of quarantine, has, however, come into wider usage, namely, what is now known as "isolation." Isolation is essentially local or sporadic quarantine, in which the person or merchandise suspected of being a vehicle of disease is separated or isolated, wherever found, or in a convenient neighboring locality, from all other persons or articles of merchandise until the danger shall have passed, or the infectious materials have been destroyed. It is found practically that this method of local or sporadic quarantine in highly civilized countries is more perfect and successful, on the whole, than the wholesale or frontier quarantine; while it inter-

feres far less with the ordinary conduct of commercial life, and is therefore less subject to the usual temptations to elude, evade or disobey quarantine regulations. Everything depends, however, in the prevention of infection by exclusion, precisely as is the case in sanitary surgery, upon the thoroughness with which the exclusion is carried out. Practically this means, in particular cases, that it depends upon the thoroughness with which the law is enforced and obeyed, and neither quarantine nor isolation can be successfully carried out in any country or in any community in which the police regulations are ignored or disobeyed. Hence it has come to pass that the less civilized nations still prefer to depend mainly upon frontier quarantine, where it is possible to keep up at least the form of prevention by exclusion; whereas, if once the infectious materials should be introduced, it is realized that little or no dependence could be placed upon the thoroughness of local or sporadic isolation. On the other hand, the more highly civilized nations, which have confidence in their ability to quarantine locally, *i.e.* to isolate sporadic cases or even infected communities, lay comparatively little stress upon frontier quarantine, well knowing how difficult and often impossible it is to make it thorough, preferring rather to depend upon such local quarantine by isolation of sporadic cases as may become necessary.

There is still considerable difference of opinion as to the value of quarantine regulations. No one can doubt that in special cases, such as the arrival of ships in well-guarded harbors, it is still possible to effect important measures of protection by the exclusion of infection through quarantine control. This is particularly true of many cities and harbors of the United States to which vessels may come after long periods at sea, bringing unmistakable evidence of infectious disease. Such vessels may well be, and often are, detained in quarantine in New York, or Boston, or San Francisco, with immense advantage to the public health.

But, on the other hand, such attempts at exclusion by quarantine regulations as have been frequently instituted along the sparsely inhabited frontiers of our Southern states, during periods of alarm because of yellow fever, are probably comparatively ineffective.

§ 3.—*Immunity, or the Prevention of Infection by Insusceptibility*

Nothing is clearer than the fact that the normal organism possesses marked powers of resistance to the invasions of infectious disease, or that some individuals offer more resistance than others. Such variations in resistance may be described as variations in susceptibility, and total insusceptibility, or perfect resistance to infectious disease, is spoken of as immunity. The term "immunity" is, however, generally limited to specific immunity, *i.e.* immunity to a particular disease or diseases. Obviously, if general immunity to infectious disease could be brought about, little attention would need to be paid either to the vehicles of infection or to the infectious elements themselves. Theoretically and practically, the production of immunity in normal organisms, whether plant or animal, is the goal of sanitary science, so far at least as infectious diseases are concerned. At present, however, this goal is not even in sight, so that strenuous efforts must still be made, and probably for a long time to come, to prevent infectious disease by the control or destruction of infectious elements in the environment, and by their exclusion from possibly susceptible individuals.

Meantime, although the goal is not in sight, some steps toward it have been taken, at least in the case of certain diseases; and although these have been dwelt upon already (p. 75), we may refer to them again at this point. The first progress consciously made in this direction was that involved in the process known as inoculation for small-pox,

and to a consideration of this process, with its natural corollaries, vaccination and serum therapy, we shall immediately return. At this point we may observe, in passing, that insusceptibility appears to be in many cases very largely a matter of physiological vigor and robust living. There can be but little question that individuals of strong constitution, well fed, well housed, well trained physically, and free from corroding care, anxiety, trouble, overwork, want of sleep and similar depressing influences are materially strengthened in their powers of resistance to disease. These matters are of fundamental importance, therefore, to the public health, and the student of sanitary science must always bear in mind the significance for the public health of conditions favoring the most perfect operation of the animal organism. Overcrowding, overwork, overexcitement, underfeeding, undersleeping, underexercise — in short, all conditions which tend to remove the organism from the normal in physical vigor — tend to the diminution of vital resistance and to the increase of susceptibility to disease. They are to be avoided as unwholesome and unsanitary, while normal, happy, vigorous, physical life is to be encouraged as probably the most fundamental and far-reaching of all sanitary measures tending to promote the public health.

§ 4. — *Insusceptibility Artificially produced by Inoculation*

One of the earliest attempts, if not the earliest, to influence directly the degree of susceptibility of the organism to an infectious disease was that of inoculation for smallpox.[1] This disease, like other well-known infectious diseases, such as the plague, appears to have been imported into Europe from Asia, where it had been known from remote antiquity. Early in the eighteenth century, and chiefly through letters of Lady Mary Wortley Montagu, it became

[1] This subject has already been discussed at length above (pp. 76–80).

known that a certain advantage to any individual liable to exposure to small-pox might be derived by direct inoculation with the virus of the disease intentionally introduced at a time when the subject was in good health, so that he should have the disease under the most favorable circumstances, rather than possibly at some time when conditions might be less favorable. This method was known and practised in the East, or at least in Turkey, at this time; and chiefly through the letters from Constantinople of Lady Montagu it became known in, and was speedily introduced into, England and America. There is no reason to doubt that such inoculations tended in a marked degree to bring about individual insusceptibility and immunity; and it is certain that under its influence the fatality of small-pox was lessened, while only a small percentage of those inoculated perished from the disease.

The objections to inoculation, however, were great; for although usually those inoculated had the disease in a relatively mild form, occasionally the severest symptoms ensued, and disfiguration was not uncommon. Moreover, as the method was essentially one of cultivation of the disease, those inoculated became veritable centres of infection; and it is said that, on the whole, the practice tended to spread the disease and, while benefiting individual cases, tended to increase the general mortality. It was gradually displaced after Jenner's discovery of vaccination by that far safer method of producing insusceptibility, and in 1840 an act of Parliament was passed rendering small-pox inoculation unlawful in England.

The student of preventive medicine and immunity may find in the history of small-pox inoculation many valuable lessons, of which the most obvious and important is the fact that the normal healthy organism in its best estate is often able to resist the onslaughts of even very virulent diseases, directly and intentionally introduced into the body. Nothing could testify more clearly to the fundamental impor-

tance in sanitary science of personal hygiene, and the immense importance of keeping the body in the best possible physiological condition. Herein, no doubt, lies the key to the explanation of the fact that in any epidemic, however widespread, a large percentage of persons escape the disease altogether, while another large percentage suffer from it but little.

On the other hand, the history of inoculation teaches that even under conditions apparently the most favorable, a few who might be supposed to be naturally exempt, owing to abundant vitality, do, nevertheless, suffer in an almost inexplicable fashion. While, therefore, it is plainly the duty of the sanitarian to do everything in his power to promote the practice of personal hygiene, it is no less his bounden duty to seek at the same time to remove the specific causes of disease from the environment. The art of hygiene is, and probably always will be, twofold: on the one hand, the creation or promotion of personal insusceptibility; and, on the other, the control or abatement of the specific inciters of disease: this double duty consisting, on the one hand, of reënforcement of the organism, and on the other, of mastery of the environment.

§ 5.—*Insusceptibility Artificially produced by that Variety of Inoculation known as Vaccination*

By far the most interesting and important attempt to bring about insusceptibility to an infectious disease is vaccination for small-pox[1]—an art now well known and fully tested all over the world. Introduced by Jenner at the end of the eighteenth century, and improved and extended by his successors, vaccination is to-day the principal weapon employed by the human race in its warfare with one of the most loathsome, and formerly one of the

[1] This subject has already been discussed briefly in another connection (p. 80).

most dreaded, of all infectious diseases. Its practice is justified not only by experience but also by experiment, for it has been conclusively and repeatedly proved by actual experiment that persons thoroughly vaccinated are for a longer or shorter time insusceptible to successful small-pox inoculation. (See *e.g.*, Report, Boston Board of Health, for 1802.)

The theory of vaccination depends simply upon the fact that comparative immunity appears to be produced in a vaccinated organism by causing it to undergo what is probably a very mild form of small-pox, or, possibly, a cognate and much milder disease — namely, small-pox of the cow, or "cow-pox." Moreover, it is the usual custom to inoculate persons whom it is desired to protect from small-pox with vaccine virus, as in the case of inoculation proper, when they are in good condition and well fitted to resist an attack of disease.

Vaccination does not differ much in principle from the earlier art of inoculation; and although it is not clear in either case how, precisely, a mild attack of the disease against which defence is sought, or of a related or modified form of the disease, such as cow-pox, confers immunity, various theories concerning this acquirement are extant, none of which can be said to be entirely satisfactory. The best is, perhaps, that of the reaction of the organism in the production of defensive antidotes to the specific virus, a matter which will be more fully explained in the next section.

There is no doubt that comparative freedom of the most highly civilized peoples from small-pox is due in part to greater cleanliness and the improvement in sanitary conditions in general, which has been so marked a feature of the past century. Resting chiefly upon this thesis, a considerable number of persons, known as anti-vaccinationists, deny altogether the efficiency of vaccination, and by dwelling upon the dangers of impure vaccine, and the possibility of

introducing the germs of other diseases into the organism, such persons object *in toto* to vaccination, and especially to vaccination made compulsory by statute. The great majority of careful students and dispassionate observers, however, while allowing a certain weight to these objections, nevertheless firmly believe that the comparative scarcity of small-pox at the present time in vaccinated peoples, though probably due in part to improved sanitary conditions, is chiefly due to the almost universal practice of vaccination.

In a disease so infectious, and even contagious, as small-pox is, it may even be doubted whether the extraordinary development of the possibilities of the spread of disease by travel and the like would not actually have caused an increase of small-pox, in spite of the general improvement in sanitary conditions, had it not been for the art of vaccination. There is reason, for example, to believe that typhoid fever has actually increased in many communities, owing to its more ready dissemination, in spite of the diminution which it must have undergone under general sanitary improvements. Typhus fever, on the other hand, has well-nigh disappeared, and disbelievers in the importance and efficiency of vaccination claim to find in the history of this disease support for their views.

§ 6.—*Nineteenth Century Progress in the Art of Inoculation and Vaccination*

The applications of pure science usually follow close upon the heels of discovery, and long before the full establishment of bacteriology steps had been taken to modify and control the action of bacteria in infectious disease.

As early as 1880 Pasteur, reflecting upon the monumental discoveries of Jenner, and upon the fact that small-pox must be supposed to be an infectious disease, perceived that a reasonable theory of vaccination, provided the germ

theory of disease were true, may be that somehow the germ of small-pox has been modified in the cow and rendered weak or "attenuated," so that when it is introduced into the human body it is no longer able to exhibit its former virulence. Filled with this idea, he accordingly undertook to produce a corresponding weakening or "attenuation" in the germs of certain common diseases such as chicken cholera and anthrax. In this attempt, in 1880, he met with surprising success; and it will be well worth while to note at this point an account of a public test of his work upon splenic fever vaccination which has been vividly portrayed by his son-in-law, M. Radot.[1]

§ 7.—*A Public Demonstration by Pasteur of the Possibility of Protective Inoculation of Certain of the Lower Animals Against Anthrax or Splenic Fever*

"It was on February 28, 1881, that Pasteur communicated to the Academy of Sciences, in his own name and in those of his two fellow-workers, the exposition of his great discovery. Loud applause burst forth with patriotic joy and pride. And yet so marvellous were the results that some colleagues could not help saying, 'There is a little romance in all this.' All this reminds one, in fact, of what the alchemist of Lesage did to the demons which annoyed him. He shut them up in little bottles, well corked, and so kept them imprisoned and inoffensive. Pasteur shut up in glass bulbs a whole world of microbes, with all sorts of varieties which he cultivated at will. Virulences, attenuated or terrible, diseases, benign or deadly, he could offer all.

"Hardly had the journals published the *compte rendu* of his communication, when the President of the Society of Agriculture in Melun, M. le Baron de la Rochette, came,

[1] "Louis Pasteur: His Life and Labors." By his Son-in-Law. From the French, by Lady Claud Hamilton. New York (Appleton), 1885.

in the name of the society, to invite Pasteur to make a public experiment of splenic fever vaccination.

"Pasteur accepted. On April 28 a sort of convention was entered into between him and the society. The society agreed to place at the disposal of Pasteur and his two young assistants, Chamberland and Roux, sixty sheep. Ten of these sheep were not to receive any treatment; twenty-five were to be subjected to two vaccinal inoculations at intervals of from twelve to fifteen days, by two vaccines of unequal strength. Some days later these twenty-five sheep, as well as the twenty-five remaining ones, were to be inoculated with the virus of virulent splenic fever. A similar experiment was to be made upon ten cows. Six were to be vaccinated, four not vaccinated; and the ten cows were afterward, on the same day as the fifty sheep, to receive inoculation from a very virulent virus.

"Pasteur affirmed that the twenty-five sheep which had not been vaccinated would perish, while the twenty-five vaccinated ones would resist the very virulent virus; that the six vaccinated cows would not take the disease, while the four which had not been vaccinated, even if they did not die, would at least be extremely ill. . . .

"The experiments began on May 5, 1881, at four kilometres' distance from Melun, in a farm of the commune of Pouilly-le-Fort, belonging to a veterinary doctor, M. Rossignol, Secretary-general of the Society of Melun. At the desire of the Society of Agriculture, a goat had been substituted for one of the twenty-five sheep of the first lot. On the 5th of May they inoculated, by means of the little syringe of Pravaz, — that which is used in all hypodermic injections, — twenty-four sheep, the goat and six cows with five drops of an attenuated splenic virus. . .

"On May 31 very virulent inoculation was effected. Veterinary doctors, inquisitive people and agriculturists formed a crowd round this little flock. The thirty-one vaccinated subjects awaiting the terrible trial stood side by

side with the twenty-five sheep and the four cows, which awaited also their first turn of virulent inoculation. Upon the proposal of a veterinary doctor, who disguised his scepticism under the expressed desire to render the trials more comparative, they inoculated alternately a vaccinated and a non-vaccinated animal. A meeting was then arranged by Pasteur and all other persons present for Thursday, June 2, thus allowing an interval of forty-eight hours after the virulent inoculation.

"More than two hundred persons met that day at Melun. The Prefect of Seine-et-Marne, M. Patinot, senators, general counsellors, journalists, a great number of doctors, of veterinary surgeons and farmers; those who believed, and those who doubted, came, impatient for the result. On their arrival at the farm of Pouilly-le-Fort, they could not repress a shout of admiration. Out of the twenty-five sheep which had not been vaccinated, twenty-one were dead; the goat was also dead; two other sheep were dying, and the last, already smitten, was certain to die that very evening. The non-vaccinated cows had all voluminous swellings at the point of inoculation, behind the shoulder. The fever was intense, and they had no longer strength to eat. The vaccinated sheep were in full health and gayety. The vaccinated cows showed no tumor; they had not even suffered an elevation of temperature, and they continued to eat quietly.

"There was a burst of enthusiasm at these truly marvellous results. The veterinary surgeons especially, who had received with entire incredulity the anticipations recorded in the programme of the experiments, who in their conversations and in their journals had declared very loudly that it was difficult to believe in the possibility of preparing a vaccine capable of triumphing over such deadly diseases as fowl cholera and splenic fever, could not recover from their surprise. They examined the dead, they felt the living. . . .

"Having suddenly become fervent apostles of the new

doctrine, the veterinary surgeons went about proclaiming everywhere what they had seen. One of those who had been the most sceptical carried his proselytizing zeal to such a point that he wished to inoculate himself. He did so with the two first vaccines, without other accident than a slight fever. It required all the efforts of his family to prevent him from inoculating himself with the most virulent virus.

"An extraordinary movement was everywhere produced in favor of vaccination. A great number of agricultural societies wished to repeat the celebrated experiment of Pouilly-le-Fort. The breeders of cattle overwhelmed Pasteur with applications for vaccine. Pasteur was obliged to start a small manufactory for the preparation of these vaccines, in the Rue Vauquelin, a few paces from his laboratory. At the end of the year 1881 he had already vaccinated 33,946 animals. This number was composed of 33,550 sheep, 1254 oxen, 142 horses. In 1882 the number of animals vaccinated amounted to 399,102, which included 47,000 oxen and 2000 horses. In 1883, 100,000 animals were added to the total of 1882."

These experiments drew universal attention to the subjects of immunity and susceptibility. It had been long recognized that there is such a thing as natural immunity as well as natural susceptibility, and the case of small-pox is familiar testimony to the fact that there is such a thing as acquired immunity. Pasteur's experiments, moreover, had abundantly demonstrated that immunity to anthrax could be artificially produced. These ideas fell in well with those concerning the toxins referred to in the third chapter (pp. 57, 59), for it was possible to see how, either by reducing the virulence of the toxins, or by accustoming the organism to them, gradually insusceptibility or virtual immunity might be produced.

To discuss all aspects of this question, interesting though it would be, would carry us too far into the domain of bac-

teriology and medicine. Suffice it to say that in one instance, at least, the studies upon this subject have already borne the richest fruit. Thanks to Behring, Roux and others, we are now able to produce at will not only the toxin of diphtheria, but also by simple procedures the antidote to this poison which is appropriately called its "antitoxin." (*Cf.* p. 83.)

§ 8.—*Insusceptibility produced by Inoculation of Antitoxins. Serum Therapy*

A logical extension of the arts of inoculation and vaccination now consists in the use of antitoxins to reënforce the natural insusceptibility of the organism, whether partial or complete. If, for example, as we have reason to believe, the specific diseases known as small-pox, plague, diphtheria, etc., are aroused by specific chemical excitants or poisons of the physiological mechanism, themselves produced by specific living excitants known as micro-organisms, it is reasonable to suppose that those animals or persons which are immune to these diseases must possess some special antidote capable of destroying the effects of the specific poisons or toxins which they generate and which are characteristic of them. By inductive reasoning of this sort Behring and Roux undertook to settle the question by gradually producing immunity to the toxin of diphtheria in horses, and then using the antitoxins presumably present in the blood of the immune horses as a curative or preventive weapon against diphtheria in man. We have already dwelt upon this subject in the preceding paragraph and elsewhere, and need not touch upon it further here. Suffice it to say, that it is now generally admitted on all sides that the antitoxin of diphtheria may be employed successfully not only to reënforce the organism already suffering from the disease, but also as a prophylactic or means of prevention in others susceptible but not yet affected. The chain of reasoning and the experi-

mental work involved in this discovery constitute one of the most beautiful examples of patient scientific work in the whole history of experimental medicine and sanitary science.

§ 9. — *Antisepsis and the Prevention of Infection by Antiseptics*

Theoretically, it should be possible to inhibit or check the progress of any infectious disease within the organism by the use of substances capable of interfering with or inhibiting the growth and multiplication of the micro-organisms involved. In practice, however, to do this is far more difficult than might be expected, so that the prevention of infection by exclusion (*asepsis*), the prevention of infection by insusceptibility (*immunity*, natural or acquired), and *external disinfection*, or the destruction and removal of infection from the environment, — which latter subject will be dealt with in the next chapter, — are infinitely more valuable methods of procedure in sanitary science. The reason for this is to be found partly in the difficulty of bringing to bear upon micro-organisms, scattered throughout masses of tissue or widely distributed in ducts or canals, agents capable of inhibiting or checking their activity, but chiefly in the fact that such agents are almost of necessity harmful to the organism which it is desired to benefit; for it is a fact which should never be forgotten that micro-organisms capable of producing infectious disease, although removed from man and the higher animals by the whole length of the animal and vegetable kingdoms, are, nevertheless, composed of protoplasm, very similar in its chemical and physical properties to that which constitutes the basis of the higher forms; so that, broadly speaking, and doubtless with many exceptions, we ought to expect a sensitiveness to inhibiting agents in the one class of organisms similar to that in the other.

Agents capable of checking or inhibiting the growth of

micro-organisms, in the way above suggested, but without necessarily killing them, are known as "antiseptics," and the process of such inhibition or checking as "antisepsis." Obviously, all disinfectants or destroyers of infection are also antiseptics; but the reverse is not true, for antiseptics are not necessarily disinfectants. When sanitary surgery was first proposed, it was generally described as antiseptic surgery, and it was held, at least by some, that its object was to inhibit the activity of organisms already introduced into the organism through wounds. Very soon, however, it became clear that the process was most successful when made aseptic rather than antiseptic; and while to-day the washings and dressings employed in surgery may and probably sometimes do, act as antiseptics, the almost universal endeavor is to secure asepsis, and not to run the risk of possibly imperfect antisepsis. We may safely grant, nevertheless, the possibility that the organism itself has antiseptic as well as disinfecting powers.

§ 10.—*Intestinal Antisepsis*

It has been proposed to introduce into the alimentary canal in certain diseases agents which, while capable of checking the progress or multiplication of the organisms of infectious disease there present, shall at the same time be harmless to the tissues lining the canal. This procedure is properly described as intestinal antisepsis; but, while well worthy of investigation, must always be subject to the drawback of constant danger of damage to the living walls by any agents powerful enough to affect the perhaps far more hardy micro-organisms of disease.

§ 11.—*The Control of Infection in Decomposition and Decay*

From the sanitary point of view, decomposition and decay must always and everywhere be regarded with sus-

picion, although they are normal processes in nature and often of high usefulness in the arts and industries of daily life. The reason for this is that they are usually effected by bacteria or other micro-organisms with which those of infections may, in theory at least, be readily associated. Moreover, the chemical products of decomposition and decay are sometimes objectionable or even dangerous, so that the race in its long experience has properly enough come to regard them with suspicion. Their prevention is obviously, therefore, often desirable, especially in the case of food products, and for this purpose antiseptics such as cold, dryness, weak acids, condensing and partial sterilization are often practically useful.

§ 12.—*Sanitary Aspects of Refrigeration and Cold Storage*

Probably the best of all antiseptics is simple cold, and this is now applied to the prevention of decomposition and decay of food almost universally. Before the introduction of the use of ice, low temperatures were sought by housewives by the keeping of foods in cold cellars, deep wells and the like; but within the past fifty years the use of ice, at least in America, has become a commonplace. The household refrigerator is a simple antiseptic device for postponing the decomposition and decay of meats, milk, vegetables, fruit and the like. More elaborate refrigerators, furnishing antisepsis in similar fashion, are provided in markets, groceries, milk-houses and like establishments; while in nearly all large cities there are nowadays huge structures known as "cold-storage" warehouses, in which vast quantities of perishable materials are successfully subjected to the antiseptic action of cold. The equipment of the best types of cold-storage warehouses is elaborate and costly, for they must be substantially and carefully built, furnished with efficient ammonia machines, or similar appliances for the produc-

tion of cold, and capable of dry ventilation to prevent excessive moisture. Cold for antiseptic purposes and the preservation of food materials is also distributed, at least in Boston, through pipes to various markets, which maintain rooms chilled to a low temperature very much as steam is circulated in winter for the heating of apartments. The sanitary value of systems of this sort is probably great, for there is reason to believe, as has been pointed out in a previous chapter (p. 259), that the germs of infectious disease do not as a rule long survive at very low temperatures.

§ 13. — *Sanitary Aspects of Desiccation, Drying, Evaporation*

A favorite and primitive method of food-preserving for meats, fruits and various other food materials has long been in use under the name of "drying," and that this method possesses important sanitary advantages seems highly probable, inasmuch as the micro-organisms of disease do not readily withstand prolonged desiccation. If, for example, fruits, meats or vegetables which it is proposed to use for food happen to be in any way infected, but are afterwards *thoroughly* dried, there is reason to believe that such desiccation is highly unfavorable to the disease germs present. Their spores, however, in some cases probably survive, and it is possible that some of the vegetative germs even may not perish; but yet the process of desiccation plainly possesses valuable sanitary advantages. These are perhaps less important than would otherwise be the case were it not for the fact that dried foods are rarely eaten without having been first not only moistened but also thoroughly cooked or heated, so that the danger of the dissemination of disease by dried foods such as dried beef, dried apricots, dried beans, etc., is probably small.

§ 14.—*Sanitary Aspects of Smoking*

A similar line of reasoning applies to the use of smoked foods, such as fish, beef or hams. In this case the process of drying is accompanied by smoking, so that whatever antiseptic or disinfecting effects may reside in smoke are added to those of desiccation. Smoked and dried herring, for example, are in many cases hung in vast quantities in comparatively close buildings, and subjected for a considerable period to the warmth and smoke of a slow fire; and inasmuch as there is reason to believe that smoke possesses important disinfecting properties due to the creosote or other materials which it contains, the process must be regarded as one of considerable sanitary significance.

Furthermore, inasmuch as smoked foods are not infrequently eaten without cookery of any kind, their treatment is of special interest to the sanitarian. In all probability, the processes to which smoked foods have been subjected, while not such as to produce complete disinfection, are nevertheless sufficient to destroy most of the germs of infectious disease. If, nevertheless, after having been smoked and dried, such foods are handled by unclean persons and then eaten raw, they constitute a source of danger similar to that which resides in all raw foods.

§ 15.—*Of Preserving.*

The process known as preserving is one in which decomposition is arrested or prevented by the use of syrups or other substances of considerable density, which in one way or another furnish an unfavorable environment to the organisms of decomposition and decay. A similar statement may probably be made in this case as in the preceding, namely, that if the food to be preserved be infected, most of the infectious organisms will probably be destroyed

in the process, though some may survive; and if later the food material of which they constitute a part be eaten without having been cooked, a certain amount of danger may ensue. The dangers in this case, also, are, however, probably small.

§ 16.—*Of Canning*

The art of canning when properly carried out consists in a total destruction of all micro-organisms present, or *disinfection*, and this process therefore belongs properly in the following chapter. It sometimes happens, nevertheless, that canned foods are only imperfectly sterilized, and when this is the case, it is clear that such foods may be bearers not only of fermentation, decomposition and decay, but, in special instances, of infection as well. At the same time, inasmuch as it is likely that the germs of putrefaction and decay will have made the contents of such cans unattractive or repulsive, there is probably very slight danger of infection from canned foods. In some cases, indeed, this may not be true, the germs remaining after partial sterilization being of a kind incapable of producing ordinary and obvious decomposition and decay. For example, sweet corn after imperfect sterilization in cans not infrequently sours more or less, owing to the presence of certain bacteria capable of producing lactic acid from the substances present, and in this case the souring may not have proceeded so far as to make the corn inedible. Under these circumstances, the possibility of the conveyance of infectious materials must be allowed; but, as has been stated, its likelihood is probably only slight.

§ 17.—*Of Pickling*

Another important method of securing disinfection and antisepsis is the art of pickling, or the preservation of foods in brines, vinegar, weak acids and the like. In this

case, while the antiseptics employed are sufficient to prevent decomposition and decay, it is unlikely that thorough sterilization or disinfection is always brought about, and the bare possibility of the distribution of disease through infected foods thus preserved must be kept in mind, although it is not probable that much disease, other than a few "sporadic" cases, actually is caused in this way.

§ 18. — *Sanitary Aspects of Pasteurizing*

A process now much used for food-preserving is that form of partial sterilization by heat known as pasteurizing. This is now much employed in the dairy industry in the pasteurizing of milk and of cream. It is of immense importance as a practical means of food-preserving, and from the standpoint of sanitary science, if carefully conducted, is also of great value. As carried out, for example, in the preservation of milk, the attempt is made to use a temperature high enough to secure the destruction of disease-producing germs, yet not so high as to produce the well-known "cooked" taste. There is much evidence of the sanitary efficiency of this process, which is always to be highly commended in the milk supply industry, but it cannot be denied that unless the pasteurizing is carried on at a high enough temperature to destroy all disease germs, such milk may still be the vehicle of infectious disease. (*Cf.* p. 287.)

§ 19. — *Of Condensing*

Condensed foods, such as condensed milk, are usually thickened by heat, but the temperature employed is often insufficient to secure in itself the complete destruction of all micro-organisms. The change in the physical condition involved in the thickening is of sanitary value, and the whole process is one of considerable sanitary importance. It is doubtful, however, whether, under certain circumstances, all germs of disease are destroyed in "condens-

ing," and the possibility that condensed foods may serve as vehicles of disease should be borne in mind, although it must be admitted that these are most likely, as a rule, safe and wholesome in this particular.

It has recently been proposed to condense milk and other food materials by cold instead of by heat. The purification of water by freezing has already been dwelt upon in a previous chapter (p. 252), and the effect of cold upon disease germs is undoubtedly, as a rule, highly prejudicial to them, so that this process, if it becomes practical, must be allowed to possess important sanitary advantages. At the same time the possibility of the survival of a small percentage of disease germs cannot, in the present state of our knowledge, be disregarded.

CHAPTER XIV

ON THE DESTRUCTION OR REMOVAL OF INFECTION. DISINFECTION AND DISINFECTANTS

§ 1.—*Definitions*

DISINFECTION is the term applied to any process by which the infectious properties of anything are removed or destroyed, and a disinfectant is any agent or factor by which this process may be brought about. Obviously, disinfection may be either partial or complete, but the term is usually applied only when the process, whatever it may be, is completely effective. Disinfection differs from asepsis in the fact that the presence of infection in the material to be disinfected is assumed, while in asepsis the endeavor is made to prevent or forestall infection. In other words, *disinfection* is in the nature of cure or correction of an infectious condition, while *asepsis* is an effort directed to the avoidance, and *antisepsis* to the inhibition or control, of infection. A little consideration will show that all disinfectants are naturally antiseptics, while antiseptics may or may not be disinfectants. Similarly, it may in any particular case happen that a disinfectant when diluted, or allowed to work for a brief period only, may act as an antiseptic; while an antiseptic, working for a long time or in unusual concentration, may become a disinfectant. As has been pointed out in the previous chapter, antisepsis is of value largely in food-preserving, to which process disinfection may also be applied. On the other hand, disinfection may often be too poisonous or drastic for application to food-preserving, and in general the term is usually applied to the purification of substances (clothing, houses,

etc.) other than food from the germs of disease, and only rarely to the arts of food-preserving.

§ 2.—*Disinfection by Chemical Agencies*

Fire is from every point of view the most valuable and effective disinfectant. We have already pointed out in a previous chapter how the disinfection of food by cookery is perhaps the most valuable part of that process, and the experience of the race has taught that it is no less effective in other directions. Infected houses, infected bedding, infected clothing, are readily disinfected by fire. Fire has always been, and probably will always continue to be, the simplest, the readiest, and the most effective of all disinfectants. It has often been suggested that the great fire of London in 1666, following as it did hard after the plague, was probably a most important factor in the purification of the city and the control of that dread disease.

The precise manner in which fire destroys infection is easy to understand. By the production of a temperature so high that no life can withstand it, and the destruction of organic matter, the germs of disease, whether animal or vegetable, are readily destroyed, and fire may perhaps be considered, by virtue of the chemical decomposition which it brings about, as essentially a chemical disinfectant.

Next in readiness and efficiency after fire come the chemical poisons, such as corrosive sublimate (mercuric chloride), carbolic acid, strong mineral acids and alkalies, sulphurous acid, formic aldehyde and the like. These, by producing chemical decompositions upon or within the cells of the organized infectious elements, so alter the chemical composition of the latter as to destroy their vital activity. In some cases, owing to special protective conditions, or forms which the infectious elements assume, all of these poisons may become for a longer or shorter time more

or less ineffective — a state of affairs which is probably common under the action of various so-called disinfectants.

§ 3. — *Disinfection by Physical Agencies*

Closely analogous to the effects just described as due to fire and poisons are those which come from heat, a moderate degree of temperature being favorable to the continued life of organized infectious elements, but higher temperatures being more and more prejudicial to them. In general, it may be stated that the boiling temperature of water destroys most ordinary infectious materials, doubtless by causing chemical changes similar to those referred to in the previous section; but, as has been shown in the previous chapter, it is often necessary to use a temperature considerably higher in order to sterilize, for example, canned foods. Moreover, microbes have been found which, though probably not capable of producing disease, are nevertheless able to withstand continuous boiling for eight hours or more. The assumption in this case is that spores are present, and are specially resistant in regard to conductivity of heat, so that their interior does not, until after a very long time, rise in temperature to the death point. It is not certain, however, whether their resistance is due to the fact that they are good non-conductors or to some special property which is not understood.

Cold in general is less effective than heat as a disinfectant, and perhaps scarcely has a place among disinfectants. Nevertheless the evidence referred to in the case of the purification of ice in freezing (p. 261) indicates that cold does in fact play a very considerable part, not only as an antiseptic, but also as a disinfectant. The experience of the race, moreover, points in the same direction. In the southern United States cold weather is rightly believed to diminish materially the dangers from yellow fever and similar diseases, and there is reason to believe that the

infectious elements of this disease, as well as of Asiatic cholera, typhoid fever, and probably many other diseases, are largely destroyed by prolonged exposure to even a moderate degree of cold, *i.e.* by temperatures in the vicinity of the freezing-point of water.

Another powerful agent of disinfection is dryness. Living things require not only a favorable temperature, but also considerable moisture; and a high degree, or a long period, of dryness undoubtedly contributes to the destruction of germ life. It is doubtful, however, whether dryness, as it occurs in periods of drought or in nature generally, is a perfect disinfectant. There is reason to believe that precisely as prolonged moderate heat is required in order to destroy infection, and precisely as prolonged low temperatures are necessary, so prolonged dryness is required unless it be brought about in the most thorough manner and by artificial means, and possibly not even then.

One of the most interesting discoveries in bacteriology of recent years was that which showed the germicidal efficiency of light. It had been known for some time to botanists that insolation, or the exposure of living organs or organisms to the light, appeared to bring about a relatively rapid disintegration of their protoplasm. Much evidence pointing in this direction was collected during the various studies which were made upon the function of chlorophyl, one view in particular (that of Pringsheim) being known as the "screen" theory, in which it was supposed that the green pigment of leaves serves as a screen to protect the underlying protoplasm from the injurious rays of the sun. It is now well known that sunlight has a marked germicidal power, and is, therefore, an important disinfectant. It is probably for this reason, in part at least, that the human race has, by experience, found sunlight so desirable in human dwellings and so effective an aid to healthy living.

Much has been hoped for, by some, from electricity as a disinfectant; but the experimental evidence thus far available does not seem to justify any great expectations in this direction. Infectious organisms are themselves so similar in their resistance to the human body, or the foods in or upon which they may be, that it does not at present seem likely that it will in the near future be possible to destroy such germs by electric currents, without, at the same time, destroying their hosts, or the media upon which they may reside.

§ 4.—*Disinfection by Mechanical Means*

The processes thus far described or referred to for the most part bring about disinfection by *destruction* of the infectious elements. The definitions given at the beginning of this chapter, however, imply the possibility, in some cases at least, of removal without destruction; and such processes are, in fact, conceivable and practicable.

Such a separation or removal may, for example, take place mechanically in filtration. If a drinking water, for instance, can be made to pass through a material of which the pores are so fine as to be impassable by the infectious elements, while yet permeable by water, then, clearly, the former may be held back while the latter may pass on. Such a mechanical filtration is plainly one form of disinfection.

Another form of mechanical disinfection is that effected by gravity. It has been pointed out above that a polluted water brought to rest and stored may be purified, in part, by sedimentation. If the infectious elements are heavier than the liquid in which they float, they may be drawn down by gravity and deposited upon the mud at the bottom of a reservoir, lake or other body of quiet water; and such sedimentation may either constitute or contribute to a genuine disinfection of a water supply.

§ 5.—*Disinfection by Biological Agencies*

If the infectious elements in any given case can be detained long enough in the absence of food, starvation must eventually ensue; and there is little doubt that in certain water supplies, and elsewhere, this condition constitutes, or may constitute, a genuine factor of disinfection. Perhaps it is not too much to say that starvation of the infectious elements is, broadly speaking, and next to fire, one of the best of all disinfectants. In regard to the cyclical changes to which infectious elements are subject, we have very little knowledge, but if old age may be conceived to be a characteristic of the lowest forms of life, —a question which is still under debate,—then this also may well constitute one of the agents of disinfection.

Finally, we may have, acting together in coöperation, two or more of the agencies already mentioned, such, for example, as cold and dryness, light and heat, or poisons and starvation, these together constituting what are called "unfavorable environments." Contrary to the opinion which was held in the earlier periods of our acquaintance with micro-organisms, we are now able to perceive that each of these must be carefully adjusted to its environment, if it is to survive long; and perhaps no factors are more effective in the control of infection than the unfavorable environments of infinite variety to which such elements must be subjected. It is probably here that we find the explanation of the sanitary improvement observed in the storage of water, ice, etc. (cf. pp. 237, 249, 261).

§ 6.—*The Problem of Disposal of the Dead*

The question of sanitary disposal of the dead concerns us chiefly so far as relates to its bearing upon the spread of infectious disease, and it is only this aspect of the subject which will be touched upon here. It has been

repeatedly stated in earlier chapters that the bacterial population of the living earth is a scavenging population, which removes from the surface of the earth the organic matters falling upon it, and converts them into inorganic matters. The same thing is true of organic matters placed at a moderate depth in the crust of the earth. The subsoil is less abundantly supplied with bacteria than the loamy layers of vegetable mould at or near the surface, but yet contains a sufficient number of them to bring about the somewhat less rapid decomposition of organic matters. Human bodies, therefore, buried in the earth, and the wooden boxes in which they are usually interred, are in time gradually mineralized, and, in favorable cases, nearly all traces of organic matter disappear. The use of metal caskets, embalming fluids (which are usually powerful disinfectants, or at least strong antiseptics), simply delay the process. If any infectious germs be present in or about the dead body, these are obviously harmless so long as they remain in the earth. The only question is, whether they may survive to be brought to the surface by earthworms or other agencies; for if so, after having been pulverized, they may be distributed by the wind. This subject has been carefully investigated by various observers, and there seems little reason to believe that infectious materials may readily be spread abroad from infected bodies buried in the earth. Moreover, there are good grounds for believing that owing to unfavorable environment, old age, or other disinfecting agencies, the infectious germs, if present, will generally not very long survive; so that we appear to be safe in concluding that from the sanitary point of view there is little to be feared from disposal of the dead by interment.

Much has been written and claimed in regard to noxious vapors arising from graveyards and in regard to graveyards, especially when crowded, as sources of disease. These ideas, however, are not founded upon good evidence,

and there is reason to believe that whatever diseases may have appeared in the neighborhood of graveyards, have had their origin elsewhere.

§ 7.—*Interment* vs. *Cremation*

If what has just been said is true, no very powerful argument can be found in sanitary science for cremation as opposed to interment. Nevertheless, the author firmly believes in cremation as the better process for the disposal of the dead, but simply for the following reasons: first, because it is speedy rather than tardy, and by cleanly combustion rather than foul decay,—fire accomplishing in a few hours a decomposition and a mineralization which require years at the hands of the bacteria; second, because of the smaller space required for the keeping of the ashes and the possibility of restricting the immense areas likely in the future to be required for cemeteries; and third, because of the removal of all ground for debate as to the possibility of damage from noxious vapors or the origin of disease from graveyards.

§ 8.—*Special Disinfectants*

The art of disinfection is a difficult and delicate one if it is desired that the disinfection in any possible case shall be absolutely thorough and complete. There is a large literature upon this subject to which many references might be given; but the following brief statements must suffice for a work devoted to the principles, rather than the practice, of sanitary science.

One of the best and most convenient disinfectants, as has already been pointed out, is fire. Almost every house, at least in temperate latitudes, is provided with a possible disinfecting apparatus in the shape of a stove, a fireplace or a furnace. The only partial exception that has come to the author's notice is the case of those houses in the interior of the United States in which natural gas is used for cook-

ing and heating. As this produces no ashes, it is said by housekeepers in these neighborhoods to be a matter of some inconvenience to get rid of dust and wastes which in other parts of the world are usually thrown into the stove or the furnace and burned.

Boiling water is an excellent disinfectant, which is usually available in almost every household. If soap be added to it, the chemical effect of the alkali is added to the physical effect of the heat, and better disinfection is brought about. The scrubbing of a floor with hot soapsuds is an admirable though primitive way of removing infection, and one of the best mechanical disinfectants is probably washing followed by thorough rubbing, which shall dislodge infectious materials from the surface of the body, from clothing, walls, etc.

The first of the chemical disinfectants to receive general attention was carbolic acid, which was introduced shortly after Pasteur's investigations referred to in the second chapter. This, though still held in high popular esteem, has been largely superseded by more effective germicides, among which we may mention corrosive sublimate and formic aldehyde (formalin). A great variety of special disinfectants is now upon the market; but this is not the place to consider their merits. One of the simplest and most useful of household disinfectants is the milk of lime, freshly made; and even when stale, lime-water is still a valuable disinfectant.

§ 9. — *Germicidal-Efficiency Tests*

In order to test the efficiency of any particular germicides, careful precautions must be taken. It is not enough to mix a measured portion of the germicide with a liquid containing bacteria, and then to observe whether or not a portion of the mixture will grow upon the ordinary bacterial soils, such as gelatine or agar, for in this case some of the germicide may have been carried over, and though dilute, may nevertheless

continue to act over a long period. Various methods have been devised in order to avoid this fundamental difficulty; but none of them are wholly satisfactory. A discussion of the question may be found in a paper by the author entitled "Germicidal Efficiency Test of a Disinfectant to be used in Railway Sanitation." *Technology Quarterly*, Vol. IV, No. 2. Boston, 1893.

§ 10.—*Present State of the Art of Disinfection*

Under state and municipal control the art of disinfection has now reached a considerable degree of efficiency. It is practicable by means of steam, or the vapors of particular substances such as sulphurous acid or formalin, to disinfect with some success buildings, ships, apartments, furniture and the like, but much still needs to be done upon this subject. Those who desire to pursue this part of the subject are referred to Dr. C. V. Chapin's valuable work on "Municipal Sanitation in the United States." Providence, R.I., 1901.

§ 11.—*Intestinal Disinfection*

An ingenious procedure has been suggested in the case of certain infectious diseases, especially such as affect the intestines or other portions of the alimentary canal, namely, that it may be possible to disinfect the alimentary canal or other special portions of the body. In the case of typhoid fever, for example, it is suggested that substances might be swallowed which, while passing through the mouth and stomach, should be harmless, but on reaching the small intestine should become decomposed or converted into antiseptics or even into disinfectants powerful enough to destroy the micro-organisms of disease yet not powerful enough to damage the general organism. In certain cases of cystitis, believed to be due to the typhoid bacillus, it is believed that substances may even now be introduced into the body which on reaching the bladder actually become effec-

tive disinfectants capable of destroying the germs of the disease. If the hopes raised by these suggestions prove to be justified, internal disinfection of special portions of the body will then have realized Professor Huxley's fancy of the cunningly devised torpedo which when swallowed shall find its way to the diseased point of the organism and by exploding there do effective work in destroying the germs of disease.

PART III

APPENDIX

APPENDIX

ON SOME POPULAR BELIEFS AS TO CERTAIN SPECIAL AND PECULIAR CAUSES OF DISEASES

"Depend upon it, in all long-established practices or spiritual formulas there has been some living truth."—J. A. FROUDE.

§ 1.—*Vagaries of Pseudo-"Sanitary Science"*

THERE is perhaps no subject in which serious errors are more prevalent than in popular hygiene. This is doubtless due to the fact that while disease has long been only too familiar and well known, any accurate knowledge of the nature and causes of disease is comparatively modern. With the advent of rational conceptions of the nature and cause of diseases, more or less misunderstanding and misconception of the application of these notions was perhaps inevitable. It seems worth while, therefore, to dwell briefly upon some of the more widespread of the fallacious notions or half-truths of sanitary science, and to define explicitly the present attitude of the best opinion of the time in regard to certain subjects relating to the public health, commonly misunderstood or misinterpreted.

§ 2.—*The Belief in Dangers from Sewer Gas*

It is commonly believed that much sickness is directly caused by the emanations of gases from sewers, drains, cesspools or other receptacles for sewage and similar foul or decomposing substances. This belief even goes so far popularly, and sometimes professionally, as to serve as the all-sufficient explanation for the occurrence of certain specific diseases, such as typhoid fever, dysentery, diphtheria and scarlet fever.

Closely examined, the belief in the efficiency of sewer gas as the cause, not only of general, but also of specific, disease appears to rest upon the idea that in some way or other poisonous gases, after having been formed in sewers, cesspools and the like by active decomposition of the foul substances therein, escape into the air, and being inhaled, either by virtue of their chemical character or by means of micro-organisms, for which they are a vehicle, produce insidious general poisoning or specific disease. It is very seldom, however, that the sewer-gas theory of disease is thus explicitly and clearly defined. More often it takes the form of the simple statement or belief that typhoid fever, dysentery, diphtheria or malaria, are directly produced by broken drains; and it is this form chiefly of the theory or belief which requires to be corrected. Sometimes the sewer-gas theory takes a more general form, vaguely hinting at obscure but powerful influences, as, *e.g.* in the following: "Now here is a removable cause of death. These gases, which so many thousands of persons are daily inhaling, do not, it is true, in their diluted condition, suddenly extinguish life. . . . In their diluted state as they rise from so many cesspools and taint the atmosphere of so many houses they form a climate congenial for the multiplication of epidemic disorders, and operate beyond all known influences of this class in impairing the chances of life." (SIMON, 1849.)

The facts with regard to sewer gas, and the part which it plays in the causing of disease, appear at present to be as follows: In the first place, there is reason to believe that the dangers of sewer gas have been very much exaggerated. There is no doubt, of course, that sewage is a decomposing liquid, and that it may, and often does, contain the germs of specific diseases. But, on the other hand, the facts that workmen frequently spend much of their time in sewers with impunity, or work upon or about sewage in sewage-purification works or on sewage farms, seem to show that experience does not confirm the idea that the gases emanating from sewage are always or necessarily dangerous. Furthermore, careful chemical and bacteriological examinations of the air of sewers have shown, not only that dangerous gases cannot ordinarily be detected in such air, but even that sewer air is singularly free from micro-organisms. A little reflection will show

that these results might have been expected, for decomposition of sewage in the sewers is seldom very advanced or extensive; while the air of sewers, being very quiet, ought to contain few bacteria.

If, now, we turn to stagnant sewage, such as might result from broken drains, or such as commonly exists in cesspools, we may reasonably expect to find more dangerous and more concentrated gases. We may even suppose that these are poisonous, and that, finding their way into human habitations, they are capable of producing sickness. There is no reason to doubt that some cases of sickness have in fact thus arisen, and to this extent the belief in sewer gas as a cause of disease is probably sound. In such cases, however, the sickness may be expected to take either the form of sudden, sharp attacks, suggestive of poisoning, or else the form of malaise and a general lowering of the vital resistance, lassitude, weakness, etc.

While thus freely granting the possible efficiency of sewer gas as a general poison and depressant, we are very far from allowing the remaining and more popular form of the belief in sewer gas, namely, that it is capable of directly producing specific diseases, such as typhoid fever and diphtheria, which absolutely require for their genesis the introduction into the body of their own peculiar germs. The popular belief must presuppose that sewer gas is somehow a vehicle for these particular germs, which are lifted by it from the sewers or cesspools, and conveyed with it into the alimentary or respiratory passages of the victim; and it is this part of the theory which cannot readily be allowed by the student of sanitary science. (See quotation from Budd, beyond, pp. 354–355.) The reader who wishes to pursue this subject further is referred to the valuable treatise by H. A. Roechling, C.E., entitled "Sewer Gas and its Influence upon Health." London, Biggs and Co., 1898.

§ 3. — *The Belief in Danger from Well Waters*

One of the most widespread of the popular sanitary beliefs of the time is that which regards with suspicion the waters of ordinary domestic wells. This is a comparatively novel point of view, for

until within the memory of the present generation the domestic well was regarded as one of the most valuable adjuncts of all well-regulated houses. Even to-day most country people, when informed by pseudo-sanitarians that grave danger resides in the family well, from which perhaps several generations of their ancestors have drunk with satisfaction and benefit, refuse to entertain the idea that serious danger can possibly exist in anything so thoroughly tested and so long highly regarded.

There is probably some truth in both points of view. The causation of cholera by the Broad Street well, referred to in a previous chapter (p. 170), and other equally undoubted examples of infection from polluted wells, have led to the generalization that serious danger often lurks in well waters. On the other hand, there are in existence innumerable examples of domestic wells which have faithfully ministered to the wants of families through long and successive generations; so that while it is true that well waters are sometimes dangerous, it is no less true that they are by no means always dangerous.

The popular confusion of the matter has probably arisen through inaccurate reasoning as to the ways in which wells may become infected. The common form of theory in this particular — at least in the United States — is essentially as follows: Inasmuch as ground water readily moves through the earth, and inasmuch, further, as polluting materials are often deposited upon or within the earth, these may be borne by the underground water, which feeds the well, from a place of deposit upon or within the earth into the well itself. The picture which may readily be drawn of such contamination, or, as it is generally called, "leaching," through the earth, is simple; and many more or less popular works upon hygiene have now for some years given illustrations showing the possible route taken by infectious materials, either from the surface of the earth, as, for example, from heaps of night soil or other excreta carelessly deposited there, or more often from leaky cesspools and the like, which may readily be so disposed in pictures, or in fact, as to appear to furnish pabulum for wells in the neighborhood.

On the other hand, comparatively little is said in such cases about the dangers of infection from the top of the well. In the opinion of the author, however, it is precisely this source of infec-

tion which is most to be dreaded, and, as a rule, is most effective; for any one who reflects upon the filtering powers of the earth must readily perceive how unlikely it is that disease germs shall be able to survive in, and pass even a few feet through soil beyond, a leaky cesspool; and that filtration and purification do, in fact, occur in ordinary domestic wells located in apparently dangerous proximity to barnyards and privies, is well shown by the chemical and bacterial composition of the waters collected from them.

Excepting those cases in which cracks or fissures in the earth allow direct communication between polluting sources and wells of drinking water, the author is strongly of the opinion that in most cases in which infection exists in wells, the polluting material has found its way in from the top. Some examples of this kind have been given in a previous chapter, one of the most famous being the celebrated Caterham case (p. 191), in which the infection of a well in the chalk, by a workman who had gone in by the top, led to an alarming epidemic among persons supplied with the well water.

When one reflects on the carelessness with which wells used as sources of drinking water are exposed to the access of filth from the top, such wells often being only loosely covered by planks, between which grasshoppers, toads or leaves frequently make their way, it is easy to see that from the boots of workmen, or from children playing on the planks, or from poultry walking about and carrying infection on their feet, pollution may readily take place. The author on one occasion noticed, for example, the following state of affairs. On a farm in an inland Massachusetts town were people sick with typhoid fever. The privy was freely open beneath and behind, and fowls were walking about under it. The same fowls a little later were seen moving aimlessly and repeatedly about upon the old and worn pieces of planking which loosely covered the domestic well top. The well was provided with a pump, and in the water drawn by the pump milk cans were washed and rinsed before receiving milk to be shipped for the Boston market. There was reason at the time to suspect that certain cases of typhoid fever in a part of the distant city among the users of this milk had been caused by milk from this farm. Whether this was the case or not, the local

conditions were certainly such as to allow ready pollution of the well water.

The truth in regard to the dangers of well waters appears to be, that if the wells are thoroughly protected at the top from the entrance of filth, they are as a rule, from the disease-producing point of view, unimpeachable, being perhaps indeed polluted with purified sewage but not often actually infected with the germs of disease. Such waters should be regarded with suspicion and carefully avoided, but yet, in the majority of cases, cannot reasonably be considered as a ready vehicle of disease.

"And I would add that certain observations which I made recently in a fever-stricken village . . . have induced me to think that of the two recognized foci for infection [in typhoid fever], the bespattered privy and the contaminated well, the former may be the one which is more commonly at work." — PROFESSOR GEORGE ROLLESTON, M.D., F.R.S.. *The Lancet*, March 6, 1869.

§ 4. — *The Belief in Dangers from Broken Drains*

Another popular belief which requires careful examination is that of the efficacy of broken drains as causes of disease. From what has been said under the first section of this chapter in regard to sewer gas, the reader will surmise that the author attaches but little importance to sewers as direct sources of infectious disease. A broken drain may, and undoubtedly often does, yield more or less of objectionable and sometimes poisonous gases, but in the present state of our knowledge of the ætiology of disease it is very difficult, if not almost impossible, to understand how the accumulation of sewage in a cellar, or leakages of sewage from broken drains, or the escape of gases from such drains, can possibly provoke infectious disease.

The belief in question has doubtless arisen, naturally enough, from a certain number of cases of coincidence between serious illness in the house and serious breaks in house drains. A well-known case of this kind occurred in Boston. The children of a family sickened and died from diphtheria; and inasmuch as on examination broken drains were discovered in the basement, the conclusion was immediately drawn that the drains were the cause

of the disease. In many houses, however, broken drains occur, and even temporary accumulations of sewage matters, without any unfavorable consequences making their appearance. In the present state of sanitary science it is far more reasonable to suppose that the diphtheria was brought into the house by milk or other uncooked foods, or by a servant suffering from a mild form of the disease, or in some other unsuspected way, than to attribute it to the occult influence of broken drains. Here, again, the gases arising from leaks and breaks may have a toxic effect, and thus lower vital resistance and increase susceptibility. To this extent, and probably to this extent only, broken drains are "sources" of disease.

§ 5. — *The Belief in Bad Smells as Causes of Disease*

There can be no doubt that evil odors may produce temporary sickness. The inhabitants of Millbury, in the suit of the latter town against the city of Worcester, Mass., testified that they had been sickened by the smells arising from the polluted Blackstone River; and the smell arising from tidal flats, covered at high tide by sewage-polluted waters and laid bare at low tide, may certainly be nauseous. On the other hand, there is no evidence whatever that typhoid fever or other infectious diseases can be directly caused in this way, so that while bad smells may be regarded as significant of putrefaction, decay, or even disease, and therefore useful warnings of trouble, they cannot in the present state of our knowledge be regarded as true sources of infectious disease. If, however, the vital resistance be lowered by such smells, they may favor, even if they cannot cause, disease. But it does not follow that bad smells do necessarily, though they certainly may, lower the vital resistance, at least so far as this can be measured by the death-rate. Thackrah, the founder of industrial hygiene, in his famous work, published in 1831, makes the following statement: —

> "The atmosphere of the slaughter-house, though sufficiently disgusting to the nose, does not appear to be at all injurious to health. The mere odors of animal substances, whether fresh or putrid, are not apparently hurtful; indeed, they seem to be often decidedly useful."

One of the most famous stinks that has been recorded — if not the most famous — was that which arose from the Thames, in

London, in 1858 and 1859. Nevertheless, as has been insisted by Dr. Budd, no very serious results followed.

"The need of some radical modification in the view commonly taken of the relation which subsists between typhoid fever and sewage was placed in a very striking light by the state of the public health in London, during the hot months of 1858 and 1859, when the Thames stank so badly.

"The late Dr. McWilliam pointed out at the time, in fitting and emphatic terms, the utter inconsistency of the facts with the received notions on the subject. Never before had Nature laid down the data for the solution of a problem of this kind in terms so large, or wrought them out to so decisive an issue. As the lesson then taught us seems to be already well-nigh forgotten, I may, perhaps, be allowed to recall some of its most salient points.

"The occasion, indeed, as already hinted, was no common one. An extreme case, a gigantic scale in the phenomena, and perfect accuracy in the registration of the results — three of the best of all the guarantees against fallacy — were combined to make the induction sure. For the first time in the history of man, the sewage of nearly three millions of people had been brought to seethe and ferment under a burning sun, in one vast open *cloaca* lying in their midst.

"The result we all know. Stench so foul, we may well believe, had never before ascended to pollute this lower air. Never before, at least, had a stink risen to the height of an historic event. Even ancient fable failed to furnish figures adequate to convey a conception of its thrice-Augean foulness. For many weeks the atmosphere of Parliamentary committee-rooms was only rendered barely tolerable by the suspension before every window of blinds saturated with chloride of lime, and by the lavish use of this and other disinfectants. More than once, in spite of similar precautions, the law courts were suddenly broken up by an insupportable invasion of the noxious vapor. The river steamers lost their accustomed traffic, and travellers pressed for time often made a circuit of many miles rather than cross one of the city bridges.

"For months together, the topic almost monopolized the public prints. Day after day, week after week, the *Times* teemed with letters filled with complaint, prophetic of calamity, or suggesting remedies. Here and there, a more than commonly passionate appeal showed how intensely the evil was felt by those who were condemned to dwell on the Stygian banks. At home and abroad, the state of the chief river was felt to be a national reproach. 'India is in revolt, and the Thames stinks,' were the two great facts coupled together by a distinguished foreign writer, to mark the climax of a national humiliation. But more significant still of the magnitude of the nuisance was the fact that five millions [of pounds] of money were cheerfully voted by a heavily taxed community to provide the means for its abatement. With the popular views as to the connection between epidemic disease and putrescent gases, this state of things naturally gave rise to the worst forebodings.

"Members of Parliament and noble lords, dabblers in sanitary science, vied

with professional sanitarians in predicting pestilence. If London should happily be spared the cholera, decimation by fever was, at least, a certainty. The occurrence of a case of malignant cholera in the person of a Thames waterman early in the summer was more than once cited to give point to these warnings, and as foreshadowing what was to come. Meanwhile, the hot weather passed away; the returns of sickness and mortality were made up, and, strange to relate, the result showed, not only a death-rate below the average, but, *as the leading peculiarity of the season*, a remarkable diminution in the prevalence of fever, diarrhœa, and the other forms of disease commonly ascribed to putrid emanations.

"After describing in scientific and forcible terms the unprecedented state of the river, Dr. Letheby adds: 'With all this condition of the Thames, however, the health of the metropolis has been remarkably good. In the corresponding period of last year (*i.e.* of the year 1857), the cases of fever, diarrhœa, and dysentery, attended in the city by the medical officers of the unions, amounted to 293 of the former, and 181 of the latter; but during the past quarter (*i.e.* the quarter of intolerable stench), they were only 202 of the former, and 93 of the latter!'

"The testimony of Dr. McWilliam, as medical supervisor of the waterguard and waterside custom-house officers, is still more to the point. The former, to the number of more than eight hundred, 'may be said to live on the river, or in the docks, in ships, or in open boats; and the latter, numbering upward of five hundred, are employed during the day in the docks, or at the various wharves of the bonded warehouses on each side of the river.' After stating that the amount of general sickness among these men was below the average of the three preceding years, and considerably below that of the forms of disease (including diarrhœa, choleraic diarrhœa, dysentery, etc.), which, in this country, noxious exhalations are commonly supposed to originate, we find the additions during the four hot months of the year from this class of complaints 26.3 below the average of the corresponding period of the three previous years, and 73 per cent less than those of 1857. In another passage this distinguished physician says: 'It is nowhere sustained by evidence that the stench from the river and docks, however noisome, was in any way productive of disease. On the contrary, there was less disease of that form to which foul emanations are supposed to give rise than usual.

"Before these inexorable figures the illusions of half a century vanish in a moment."—William Budd, *Typhoid Fever, its Nature, Mode of Spreading and Prevention*, pp. 148–151. London, 1873.

Dr. Ord reported to the Privy Council in 1859 that in 1858 (the year of the worst stench) steamboat men on the Thames suffered severely from languor, headache, sore throat, nausea, giddiness, mental confusion, etc. (in other words from symptoms of poisoning). In 1859 the river was much better, and very few such symptoms occurred: "The greater weekly mortality has not coincided with

the greater development of the stench, our most ready measure of the foulness of the stream. . . . In both years the presence of sulphuretted hydrogen in the river atmosphere was shown by the rapid blackening of paper soaked in solutions of lead, and by the discoloration of the paint of vessels." — *Second Report, Medical Officer of the Privy Council, for* 1859, p. 55. London, 1860.

§ 6. — *Is Consumption Inherited?*

The discovery by Koch, in 1882, that tuberculosis is accompanied, and apparently originated, by a specific bacillus, has caused the popular belief that consumption is hereditary to be seriously questioned. The results of numerous experiments made by competent observers have tended to show that the germs of the disease are not often conveyed directly from parent to offspring, while the observations of pathologists have, as a rule, tended to indicate that new-born children of consumptive parents are free from all signs of the disease. On the other hand, no belief probably is more firmly rooted in the human race than that "consumption runs in families," and is peculiarly an hereditary disease. How, it may well be asked, can these opposing results of experience and experiment be harmonized? The answer is simple. If we assume, in accordance with the results of experiment, that the germs themselves are not ordinarily inherited, we are not thereby prevented from supposing that those special constitutional qualities which allowed the disease to prevail in one generation are inherited, so that, while the germs themselves may not be carried on directly from generation to generation, a soil suitable for their development and multiplication is nevertheless inherited, and only requires to be sown with the germs in question in order to give rise to the disease. In other words, while the disease itself and its agents are ordinarily not inherited, a predisposition to the disease, a tendency, a weakness, or a condition favorable to the disease, may be thus derived.

For example, a child of consumptive parentage may conceivably be born absolutely free from the germs of disease, yet of such constitution as to be highly susceptible to them; and it is easy to see how, even within a few days, such a child may become infected

from the milk or the lips of a tuberculous mother. This solution of the problem is interesting, as allowing place both for the instinctive experience of the race which seems to show that the disease is inherited, while in reality only showing that the disease runs in families, such "running" being due, not to the inheritance of the disease itself, but to the action of contagion from infected elders upon susceptible offspring which have a tendency or predisposition to the disease.

§ 7. — *The Probable Truth about Endemic Disease*

One of the common phrases of sanitary science, especially in popular discussions, is that which describes disease as "endemic" in certain localities. What is meant by the expression is that the disease appears to have, in the localities mentioned, a local and permanent residence. Expressions of this kind, however, at least when applied to infectious disease, have very little value. It was formerly said, for example, that typhoid fever was "endemic" in Lowell and Lawrence, by which was meant the obvious fact that it was always to be found there, with the added implication that there was something peculiar in the local conditions, such, for example, as a special soil, ground water, or other local condition, which made these cities an especially favorable dwelling-place for the disease.

The fact was undoubtedly correct: typhoid fever was always or nearly always present; but the implication was incorrect. There was nothing in Lowell or Lawrence essentially different in respect to soil or people or any other particular (with one exception) from the conditions prevailing in Concord, Manchester, Nashua or Haverhill, neighboring cities in the same valley. The one exception was the water supply, by which the germs of typhoid fever were distributed among the citizens. Once this element of infection was removed, the disease nearly disappeared, and ceased to be endemic. As a matter of fact, it had never been endemic, but was rather constantly epidemic.

Careful investigation is required, therefore, in any particular case before we are justified in concluding that any particular disease is endemic, *i.e.* at home in nature in any particular locality.

Such cases do perhaps exist, as, for example, in the case of Asiatic cholera in Calcutta, and of malaria in the Roman campagna; but recent advances in the study of the latter disease have thrown grave doubt on its necessary endemicity even in the campagna, and such cases are nowadays to be regarded as established only after the most careful investigation.

§ 8. — *The Belief in Dangers from Atmospheric and Telluric Disturbances*

One of the popular beliefs which meets the student of sanitary science when he undertakes to discover the sources of epidemic disease is an indefinite and occult feeling that there has been something mysterious and yet influential in the earth or the air sufficient to account for the prevalence of the epidemic in question, if there happens to be one. The author, in the course of his studies of typhoid fever, for example, has frequently been told that in the opinion of such and such persons the disease prevailing at the moment was due to "a late spring," or "a hard winter," or to the turning up of the soil in the neighborhood, or to prolonged cloudy weather, or some other similar indefinite or obscure cause, when perhaps in reality the true cause was an infection of milk supply or water supply, or a simple case of secondary infection from person to person.

This form of belief is probably the survival of a very ancient and natural tendency in the human race to connect any unusual yet well-remembered event with other unusual or especially disastrous phenomena antecedent to the first in time, and marks an interesting reversion to theories commonly accepted in the childhood of the race, but long since outgrown. Nothing better illustrates the fundamental value of the germ theory of disease in placing upon definite material particles the responsibility for causation, than the ease with which such primitive theories may by its use be discredited. Sanitary science readily allows the direct physiological action upon the organism of atmospheric and telluric circumstances in exalting or depressing the vital resistance, but strenuously denies the direct causation of specific infectious diseases by such obscure or occult influences.

§ 9. — *The Belief in Dangers from Damp Cellars*

It has long been accepted as a fact by the more intelligent of the human race that damp cellars are unwholesome abodes, but the precise reason for this belief, other than the simple results of experience, has always been hard to discover. When the germ theory of disease became prominent, it was felt by many that the solution of this problem was at hand, for what more favorable place for the growth of germs than damp, dark cellars, known to be inhabited by moulds, and presumably therefore the favorable habitat of innumerable other micro-organisms?

Investigation, however, has not tended to confirm this theory, for the air of cellars, at least of quiet cellars, is practically germ free, while upon their walls and floors there is often sufficient dampness to keep any germs which may exist there from rising into the air. The truth appears to be rather that certain depressing physiological or constitutional effects are produced upon the human organism by the conditions which prevail in damp cellars, and that these are efficacious in the production of specific disease only by virtue of such depression, which lowers the vital resistance and increases the susceptibility to specific disease germs derived from any source whatsoever. The whole subject, nevertheless, undoubtedly requires further elucidation.

It is interesting to note, in passing, that under the Public Health Act of 1875, Section 41, new cellar dwellings were prohibited, and old ones regulated, in England and Wales.

§ 10. — *The Belief in Dangers from Human Breath*

One of the greatest blessings of the germ theory of disease has been the allaying of the fears of mankind in respect to the dangers lurking in human breath. Formerly the bedside of an infected patient was shunned as a place of extreme danger, largely because the breath, which seemed to be the very essence alike of the patient's life and of his disease, was believed to be loaded with infection, so that all who came within its reach — and that meant, of course, within the apartment occupied by the patient — were exposed to the gravest dangers. Bacteriology, however, has largely done away with this dread, for it has actually demon-

strated the amazing fact that the expired breath of the ordinary human being is practically germ free. The reason for this appears to be that the inspired air is not only drawn in through narrow and moist passages, more or less lined with filtering hairs and projections which cause the current of air to impinge upon moist surfaces, but is also passed through and over porous tissues saturated with moisture by which any micro-organisms suspended in the air are retained. A person coughing or breathing very hard, or even while speaking loudly, may, indeed, charge the expired breath with finely divided particles of sputum loaded with disease germs, — a fact probably of importance in the causation of tuberculosis, — but the idea that the breath of a diseased person necessarily, or even usually, conveys that disease is no longer tenable.

If it be asked what becomes of the micro-organisms thus detained within the lungs and on the respiratory passages, the answer probably is that they are slowly swept upward by the cilia lining the bronchi and trachea, until finally, arriving in the mouth, they are either swallowed and pass downward into the alimentary canal, or else discharged as expectoration or otherwise from the mouth or nose.

§ 11. — *The Probable Truth about Danger from Putrefaction and Decay*

Much is heard about the dangers of foods spoiled or partially decomposed, especially because these processes are popularly supposed to give rise readily to the production of poisonous chemical bodies roughly classed as "ptomaines." Fortunately, most food which is undergoing putrefaction and decay is not appetizing, and is, therefore, sedulously avoided. On the other hand, certain cheeses, butter, and other food materials are normally partially decomposed or "ripened" by bacteria. The truth appears to be that in rare cases products may be formed by the presence of dangerous bacteria, which are really prejudicial, or even poisonous, to the human organism, but that such bodies are not formed or met with nearly as often as popular rumor would lead one to suppose. In a certain number of cases the poisoning, if certainly present, is due to mineral matters, such as salts of lead, or tin, or copper, and not to organic poisons of any kind.

§ 12. — *Spoiled Meats*

The dangers from spoiled meat are probably comparatively slight, at least broadly speaking, because meat which is so spoiled as to be dangerous is generally distasteful. Nevertheless, it is possible that canned or preserved meats, or meats which have been too much decomposed before cooking, do occasionally give rise to serious trouble.

§ 13. — *Ice-cream Poisoning*

Numerous cases are on record in which persons have suffered severely after eating ice-cream. In some of these cases mineral poisons are to be regarded as the probable source of trouble, having found their way in either with the materials used for flavoring, or from uncleanness in the freezers, or from other sources unknown. Rarely, it may be that the milk or cream employed has contained organisms capable of producing harmful fermentations; but while it is generally assumed that these cases are true cases of ptomaine poisoning, much uncertainty exists as to the facts. It is easy for a physician, or for any one, called to see patients suffering after having eaten ice-cream, or similar foods, to pronounce an opinion that the case is one of ptomaine poisoning. The more cautious student of sanitary science will, however, require considerable evidence before finally concluding that such is the case, for he will remember that typhoid fever in cities has often been erroneously attributed to ice, to water and to various other sources, when in reality it was due perhaps to none of the alleged causes, but to something totally different and unsuspected, as, for example, milk, and in other cases was not even typhoid at all, but perhaps trichinosis.

§ 14. — *Canned Foods*

All that has been said in § 9, 10, 11 applies, with equal force, to canned foods alleged to be the causes of disease. Unquestionably these, if imperfectly sterilized, may be spoiled and contain living micro-organisms. It is quite possible that in certain cases nausea or even severe poisoning has been caused by the use of such foods, owing to poisonous products of decomposition present

in them. As a rule, however, the senses of taste and smell in such cases may be depended upon for warning; and the processes employed in canning, and the conditions of unfavorable environment which they furnish to disease germs, must be sufficient, in the great majority of cases, to cause the destruction of these more specific micro-organisms. This subject has already been dwelt upon at some length (p. 331).

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